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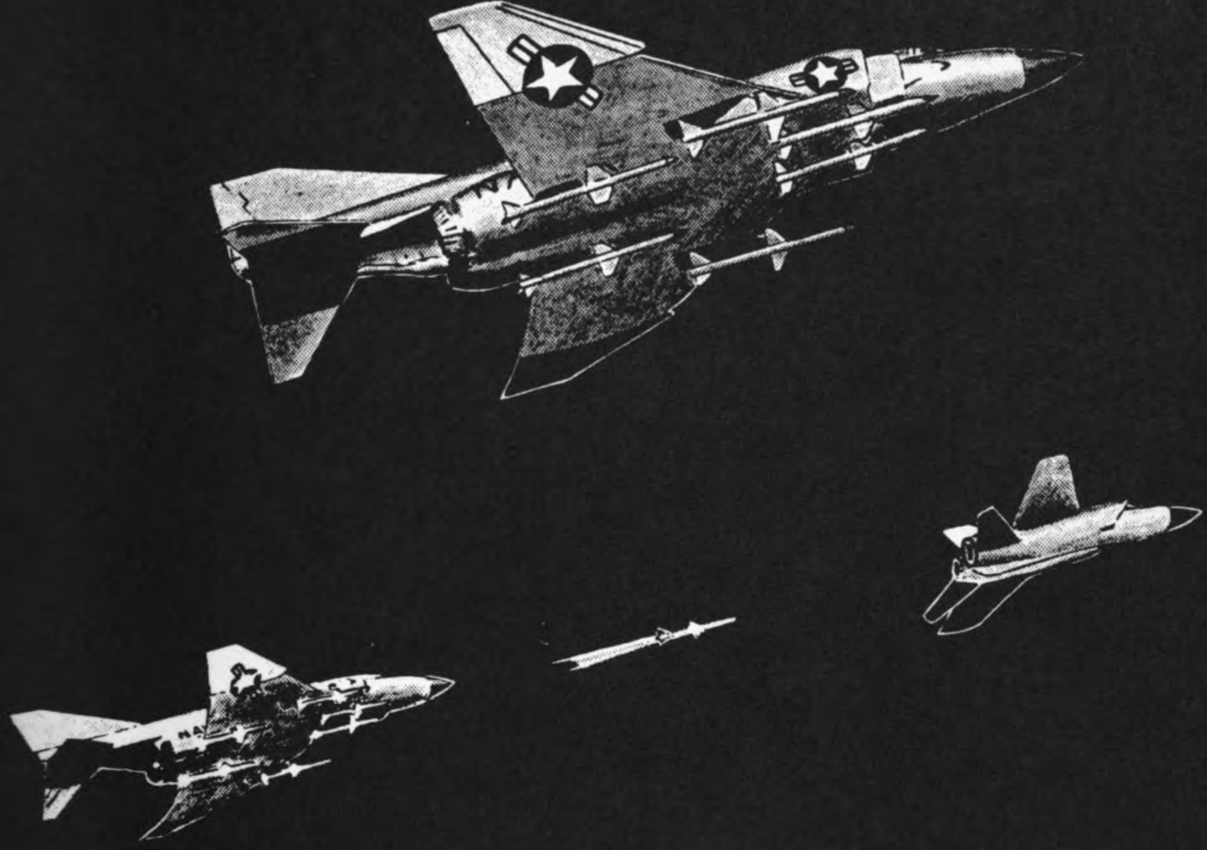

AVIATION

FIRE CONTROL TECHNICIAN 1 & C

NAVAL TRAINING COMMAND

RATE TRAINING MANUAL NAVTRA 10390-C

THE UNITED STATES NAVY

GUARDIAN OF OUR COUNTRY

The United States Navy is responsible for maintaining control of the sea and is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war.

It is upon the maintenance of this control that our country's glorious future depends; the United States Navy exists to make it so.

WE SERVE WITH HONOR

Tradition, valor, and victory are the Navy's heritage from the past. To these may be added dedication, discipline, and vigilance as the watchwords of the present and the future.

At home or on distant stations we serve with pride, confident in the respect of our country, our shipmates, and our families.

Our responsibilities sober us; our adversities strengthen us.

Service to God and Country is our special privilege. We serve with honor.

THE FUTURE OF THE NAVY

The Navy will always employ new weapons, new techniques, and greater power to protect and defend the United States on the sea, under the sea, and in the air.

Now and in the future, control of the sea gives the United States her greatest advantage for the maintenance of peace and for victory in war.

Mobility, surprise, dispersal, and offensive power are the keynotes of the new Navy. The roots of the Navy lie in a strong belief in the future, in continued dedication to our tasks, and in reflection on our heritage from the past.

Never have our opportunities and our responsibilities been greater.

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PREFACE

This Rate Training Manual is one of a series of Rate Training Manuals prepared especially for enlisted personnel of the Navy and Naval Reserve who are preparing for advancement to AQ1 and AQC.

The Manual of Qualifications for Advancement, NavPers 18068-C (current through change 2), has been used as a guide in the selection of content for this manual. Trainees should become familiar with the qualifications for advancement prior to studying this manual.

All qualifications for advancement are not covered in this manual. Essential background information for the study of this manual and additional quals coverage are contained in the following Rate Training Manuals:

Basic Electronics Vol. 1, NavPers 10087-C, chapter 2.

Basic Electronics Vol. 2, NavPers 10087-C, chapters 6, 7 and 10.

Synchro, Servo, and Gyro Fundamentals, NavPers 10105, chapters 5 and 6.

Military Requirements for PO 1 & C, NavPers 10057-C, chapter 10.

This Rate Training Manual has been prepared by the Navy Training Publications Center, NAS Memphis, Millington, Tennessee, for the Naval Training Command. Credit is given to the Naval Air Technical Training Center, NAS Memphis, Millington, Tennessee; the Naval Examining Center, Great Lakes, Illinois; and the Naval Air Systems Command for technical reviews.

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CONTENTS

Chapter **Page**

1. Aviation Fire Control Technician rating 1
2. Management 11
3. Material control 46
4. Maintenance procedures and special problems 69
5. Avionics support equipment 86
6. Antennas and waveguide plumbing 135
7. Special components, circuits, and systems 166
8. Typical airborne missile control system 208

Index 259

READING LIST

United States Armed Forces Institute (USAFI) courses for additional reading and study are available through your Educational Services Officer.* The following courses are recommended.

D-166 Advanced Algebra
D-177 Geometry II
D-188 Trigonometry
E-291 Physics II
G-544 Personnel Management

*"Members of the United States Armed Forces Reserve components, when on active duty, are eligible to enroll for USAFI courses, services, and materials if the orders calling them to active duty specify a period of 120 days or more, or if they have been on active duty for a period of 120 days or more."

CHAPTER 1

AVIATION FIRE CONTROL TECHNICIAN RATING

This Rate Training Manual is designed to aid the AQ 2 to advance to AQ1 and the AQ1 to advance to AQC. It is based primarily on the professional requirements or qualifications for AQ1 and AQC as specified in the latest revision of the Manual of Qualifications for Advancement, NavPers 18068-C. In preparing for the examination for advancement, this manual should be studied in conjunction with the manuals or publications listed in the Bibliography for Advancement Study, NavTra 10052 (Series) under the AQ section.

Most of the contents of this training manual involve the technical subject matter with which the Aviation Fire Control Technician must become proficient. Other areas covered include the responsibilities required of the senior AQ's concerning maintenance organization, administration, supervision, and procedures. Supply is also discussed, but only at a level of familiarization which is necessary for all naval personnel who are concerned with maintenance.

ENLISTED RATING STRUCTURE

The present enlisted rating structure includes two types of ratings: general ratings and service ratings.

GENERAL RATINGS are designed to provide paths of advancement and career development. A general rating identifies a broad occupational field of related duties and functions requiring similar aptitudes and qualifications. General ratings provide the primary means used to identify billet requirements and personnel qualifications. Some general ratings include service ratings; others do not. Both Regular Navy and Naval Reserve personnel may hold general ratings.

Subdivisions of certain general ratings are identified as SERVICE RATINGS. These service ratings identify areas of specialization within the scope of a general rating. Service ratings are established in those general ratings in which specialization is essential for efficient utilization of personnel. Although service ratings can exist at any petty officer level, they are most common at the PO3 and PO2 levels. Both Regular Navy and Naval Reserve personnel may hold service ratings.

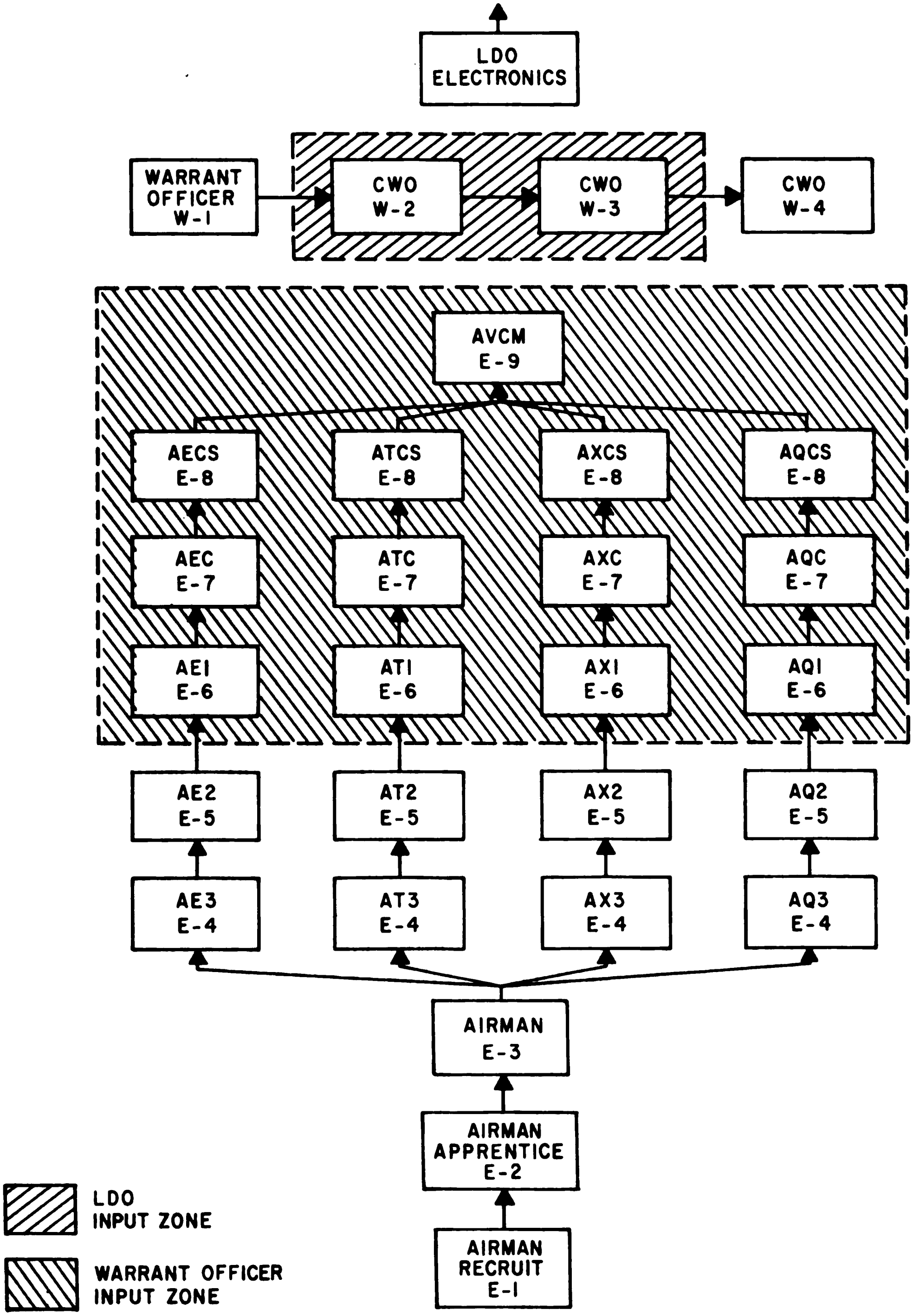
AQ RATING

AQ1 and AQC are rates within the AQ general rating and are included in the Navy Occupational Group IX (Aviation) ratings.

Where occupational content is related, general ratings have been combined at the E-8 and E-9 levels to form broader occupational fields. In the AQ rating, in order to advance to Senior Chief Petty Officer (E-8), Chief Petty Officers (E-7) will be required to become conversant with the duties and responsibilities of the other avionics ratings (AE, AX, and AT).

At pay grade E-9, the AQ rating loses its identity; all of the avionics ratings are compressed into one rating at the E-9 level. The AECS, AQCS, ATCS, or AXCS who is selected for advancement becomes a Master Chief Avionics Technician (AVCM). Figure 1-1 illustrates the paths of advancement from Recruit to Master Chief Avionics Technician, Warrant Officer, or Limited Duty Officer.

Shaded areas in figure 1-1 indicate career stages from which qualified men may advance to



AE.1

Figure 1-1.—Paths of advancement.

Warrant Officer (W-1) and selected Commissioned Warrant Officers (W-2 or W-3) may advance to Limited Duty Officer (LDO).

The AQ must be able to inspect and perform organizational and intermediate maintenance on aircraft weapon systems (including weapons control radar, computers, computing sights, gyroscopes, accessories, and related equipment) and air launched guided missile equipment.

In addition, the AQ is responsible for insuring that all test equipment is in operating condition, and that any repairs or calibration needed is performed in accordance with current instructions.

Assignments available to the AQ's vary widely. In addition to the various types of maintenance activities to which lower rated personnel are assigned (discussed in AQ 3 & 2, NavTra 10387(Series)), Second Class and above are eligible for assignment to instructor duty as well as a number of other desirable shore billets. Most of these billets are under the management control of BuPers and are directly associated with training. Others are associated with research, testing, or evaluation. Some of the more desirable billets to which the AQ may be assigned are described in the following paragraphs.

Instructor duty is available at the Naval Air Technical Training Center, Millington, Tenessee, in the following schools:

1. Avionics Technician Course (Class A).
2. Advanced First Term Avionics Course (Class B).
3. Avionics Advanced Course (Class B).
4. Aviation Officers School (Class O).

In addition to the above listed instructor billets, the AQ may be assigned to instructor duty with a Naval Air Maintenance Training Unit (NAMTU). NAMTU's are located at shore stations on both coasts. Personnel assigned to this duty are first sent to Naval Air Maintenance Training Group headquarters at Millington, Tennessee, for a period of indoctrination and instruction.

Instructor billets are normally filled on a voluntary basis. Detailed information concerning assignment to instructor duty is contained in the Enlisted Transfer Manual, NavPers 15909 (Series).

Chief Aviation Fire Control Technicians are also eligible for assignment to duty with the Naval Examining Center, Great Lakes, Illinois, as Item Writers. CPO's assigned to the Examining Center assist in the preparation of Navy-wide advancement examinations for enlisted personnel.

Senior Chief Aviation Fire Control Technicians are eligible for assignment to duty with the Navy Training Publications Center (NTPC) NAS, Memphis, Millington, Tennessee, as Technical Writers. CPO's assigned to NTPC assist in the preparation and revision of Rate Training Manuals and/or Correspondence Courses for the avionics ratings.

There are a number of special programs and projects to which enlisted personnel may be assigned. Some of these involve research; others may involve testing or evaluation. An example of such an assignment is with the Personnel Research Division (PRD) of the Naval Aviation Intergrated Logistic Support Center (NAILSC), Naval Air Test Center, Patuxent River, Maryland. Their mission is to develop recommended personnel requirements for squadrons operating and maintaining the latest types of weapons systems.

For a listing of other special programs and projects, reference should be made to the Enlisted Transfer Manual. Others are also announced from time to time in BuPers Notices.

Personnel may indicate their desire for assignment to a specific program or project by indicating it in the "remarks" block of their Rotation Data Card.

As a petty officer, you are already aware of the importance of the AQ rating to naval aviation. Pilots and aircrewmen depend upon the AQ for the efficient operation of the systems for which he is responsible. As improved weapons systems are developed, the AQ's job involves new and greater responsibilities; from the lowest level up, he must possess greater technical skills than ever before.

When advanced to AQ1 or AQC, even more responsibilities are to be yours; in other words, you must possess more than technical skills. You must assume greater responsibility not only for your own work, but also for the work of others who serve under you. Briefly, the AQ1 or AQC must be a skilled technician, supervisor, inspector, and instructor, as well as an accomplished military leader. First class and chief petty officers are therefore vitally concerned with the Naval Leadership Program.

As a result of the Naval Leadership Program, a considerable amount of material related to naval leadership for first class and chief petty officers is available. Studying this material will make you aware of your many leadership responsibilities as a first class or chief petty officer and will also be of great help in developing leadership qualities. It will not in itself, however, make you a good leader. Leadership principles can be taught, but a good leader acquires the quality of leadership only through hard work and practice.

As you study this material concerning leadership traits, keep in mind that probably none of our most successful leaders possessed all of these traits to a maximum degree, but a weakness in some traits was more than compensated for by strength in others. Critical self-evaluation will enable you to realize the traits in which you are strong, and to capitalize on them. At the same time you must constantly strive to improve on the traits in which you are weak.

Your success as a leader will be decided, for the most part, by your achievements in inspiring others to learn and perform. This is best accomplished by personal example.

ADVANCEMENT

By this time, you are probably well aware of the personal advantages of advancement—higher pay, greater prestige, more interesting and challenging work, and the satisfaction of getting ahead in your chosen career. By this time, also, you have probably discovered that one of the most enduring rewards of advancement is the training you acquire in the process of preparing for advancement.

The Navy also profits by your advancement. Highly trained personnel are essential to the functioning of the Navy. By advancement, you increase your value to the Navy in two ways: First, you become more valuable as a person who can supervise, lead, and train others and second, you become more valuable as a technical specialist and thus make far-reaching contributions to the entire Navy.

Since you are studying for advancement to PO1 or CPO, you are probably already familiar with the requirements and procedures for advancement. However, you may find it helpful to read the following sections. The Navy does not stand still. Things change all the time, and it is possible that some of the requirements have changed since the last time you went up for advancement. Furthermore, you will be responsible for training others for advancement; therefore, you will need to know the requirements in some detail.

HOW TO QUALIFY FOR ADVANCEMENT

To qualify for advancement, a person must:

1. Have a certain amount of time in grade.
2. Complete the required military and professional training manuals.
3. Demonstrate the ability to perform all the PRACTICAL requirements for advancement by completing applicable portions of the Record of Practical Factors, NavTra 1414/1 (formerly NavPers 760).
4. Be recommended by his commanding officer.
5. Demonstrate his KNOWLEDGE by passing a written examination on (a) military requirements, and (b) professional qualifications.

Remember that the requirements for advancement can change. Check with your educational services office to be sure that you know the most recent requirements.

When you are training lower rated personnel, it is a good idea to point out that advancement is not automatic. Meeting all the requirements makes a person ELIGIBLE for advancement. Such factors as the score made on the written examination, length of time in service, performance marks, and quotas enter into the final determination of who will actually be advanced.

HOW TO PREPARE FOR ADVANCEMENT

Preparation for advancement includes studying the qualifications, working on the practical factors studying the required Rate Training Manuals and studying any other material that may be specified. To prepare yourself for advancement or to help others prepare for advancement, you will need to be familiar with (1) the "Quals" Manual, (2) the Record of Practical Factors, NavTra 1414/1, (3) a NavTra publication called Bibliography for Advancement Study, NavTra 10052 (Series) and (4) Rate Training Manuals. The following sections describe these materials and give some information on how to use them to the best advantage.

"Quals" Manual

The Manual of Qualifications for Advancement, NavPers 18068 (Series), gives the minimum requirements for advancement to each rate within each rating. This manual is usually called the "Quals" Manual, and the qualifications are of two general types: (1) military requirements, and (2) professional or technical qualifications. Military requirements apply to all ratings rather than to any one rating alone. Professional qualifications are technical or professional requirements that are directly related to the work of each rating.

Both the military requirements and the professional qualifications are divided into subject matter groups. Then, within each subject matter group, they are divided into PRACTICAL FACTORS and KNOWLEDGE FACTORS.

The qualifications for advancement and a bibliography of study materials are available in your educational services office. The "Quals" Manual is changed more frequently than Rate Training Manuals are revised. By the time you are studying this training manual, the "quals" may have been changed. Never trust any set of "quals" until you have checked the change number against up UP - TO - DATE copy of the "Quals" Manual.

In training others for advancement, emphasize these three points about the "quals":

1. The "quals" are the MINIMUM requirements for advancement. Personnel who study MORE than the required minimum will have a great advantage when they take the written examinations for advancement.

2. Each "qual" has a designated rate level–chief, first class, second class, or third class. You are responsible for meeting all "quals" specified for the rate level to which you are seeking advancement AND all "quals" specified for lower rate levels.

3. The written examinations for advancement will contain questions relating to the practical factors AND to the knowledge factors of BOTH the military requirements and the professional qualifications.

Record of Practical Factors

A special form known as the Record of Practical Factors, NavTra 1414/1, is used to record the satisfactory performance of the practical factors. This form lists all military and all professional practical factors. Whenever a person demonstrates his ability to perform a practical factor, appropriate entries must be made in the DATE and INITIAL columns. As a PO1 or CPO, you will often be required to check the practical factor performance of lower rated personnel and to report the results to your supervising officer.

As changes are made periodically to the "Quals" Manual, new NavTra 1414/1 forms are provided when necessary. Extra space is allowed on the Record of Practical Factors for entering additional practical factors as they are published in changes to the "Quals" Manuals. The Record of Practical Factors also provides space for recording demonstrated proficiency in skills which are within the general scope of the rate but which are not identified as minimum qualifications for advancement. Keep this in mind when you are training and supervising other personnel. If a person demonstrates proficiency in some skill which is not listed in the "quals" but which is within the general scope of the rate, report this fact to the supervising officer so that an appropriate entry can be made in the Record of Practical Factors.

When you are transferred, the Record of Practical Factors should be forwarded with your service record to your next duty station. It is a good idea to check and be sure that this form is actually inserted in your service record before you are transferred. If the form is not in your record, you may be required to start all over again and requalify in practical factors that have already been checked off. You should also take some responsibility for helping lower rated personnel keep tract of their practical factor records when they are transferred.

A second copy of the Record of Practical Factors should be made available to each man in pay grades E-3 through E-8 for his personal record and guidance.

NavTra 10052

Bibliography for Advancement Study, NavTra 10052 (Series) is a very important publication for anyone preparing for advancement. This publication lists required and recommended Rate Training Manuals and other reference material to be used by personnel working for advancement. NavTra 10052 (Series) is revised and issued once each year by the Naval Training Support Command. Each revised edition is identified by a letter following the NavTra number. When using this publication, be SURE you have the most recent edition.

The required and recommended references are listed by rate level in NavTra 10052 (Series). It is important to remember that you are responsible for all references at lower rate levels, as well as those listed for the rate to which you are seeking advancement.

Rate Training Manuals that are marked with an asterisk (*) in NavTra 10052 (Series) are MANDATORY at the indicated rate levels. A mandatory training manual may be completed by (1) passing the appropriate Enlisted Correspondence Course that is based on the mandatory training manual, (2) passing locally prepared tests based on the information given in the mandatory training manual, or (3) in some cases, successfully completing an appropriate Navy school.

When training personnel for advancement, do not overlook the section of NavTra 10052 (Series) which lists the required and recommended references relating to the military requirements for advancement. All personnel must complete the mandatory military requirements training manual for the appropriate rate level before they can be eligible to advance. Also, make sure that personnel working for advancement study the references which are listed as recommended but not mandatory in NavTra 10052 (Series). It is important to remember that ALL references listed in NavTra 10052 (Series) may be used as source material for the written examinations, at the appropriate levels.

Rate Training Manuals

There are two general types of Rate Training Manuals. Manuals (such as this one) are prepared for most enlisted rates and ratings, giving information that is directly related to the professional qualifications for advancement. Basic manuals give information that applies to more than one rate and rating.

Rate Training Manuals are revised from time to time to bring them up to date. The revision of a Rate Training Manual is identified by a letter following the NavTra number. You can tell whether a Rate Training Manual is the latest edition by checking the NavTra number (and the letter following the number) in the most recent edition of List of Training Manuals and Correspondence Courses, NavTra 10061 (Series).

Rate Training Manuals are designed for the special purpose of helping naval personnel prepare for advancement. By this time, you have probably developed your own way of studying these manuals. Some of the personnel you train, however, may need guidance in the use of Rate Training Manuals. Although there is no single "best" way to study a training manual, the following suggestions have proved useful for many people:

1. Study the military requirements and the professional qualifications for your rate before you study the training manual, and refer to the "quals" frequently as you study. Remember, you are studying the training manual primarily to meet these "quals."
2. Before you begin to study any part of the training manual intensively, get acquainted with the entire manual. Read the preface and the table of contents. Check through the index. Thumb through the manual without any particular plan, looking at the illustrations and reading bits here and there as you see things that interest you.
3. Look at the training manual in more detail, to see how it is organized. Look at the table of contents again. Then, chapter by chapter, read the introduction, the headings, and the subheadings. This will give you a pretty clear picture of the scope and content of the manual.

4. When you have a general idea of what is in the training manual and how it is organized, fill in the details by intensive study. In each study period, try to cover a complete unit–it may be a chapter, a section of a chapter, or a subsection. The amount of material you can cover at one time will vary. If you know the subject well, or if the material is easy, you can cover quite a lot at one time. Difficult or unfamiliar material will require more study time.

5. In studying each unit, write down questions as they occur to you. Many people find it helpful to make a written outline of the unit as they study, or at least to write down the most important ideas.

6. As you study, relate the information in the training manual to the knowledge you already have. When you read about a process, a skill, or a situation, ask yourself some questions. Does this information tie in with past experience? Is this something new and different? How does this information relate to the qualifications for advancement?

7. When you have finished studying a unit, take time out to see what you have learned. Look back over your notes and questions. Without looking at the training manual, write down the main ideas you have learned from studying this unit. Do not just quote the manual. If you cannot give these ideas in your own words, the chances are that you have not really mastered the information.

8. Use Enlisted Correspondence Courses whenever you can. The correspondence courses are based on Rate Training Manuals or other appropriate texts. As mentioned before, completion of a mandatory Rate Training Manual can be accomplished by passing an Enlisted Correspondence Course based on the training manual. You will probably find it helpful to take other correspondence courses, as well as those based on mandatory training manuals. Taking a correspondence course helps you to master the information given in the training manual, and also gives you an idea of how much you have learned.

INCREASED RESPONSIBILITIES

When you assumed the duties of a PO3, you began to accept a certain amount of responsibility for the work of others. With each advancement, you accept an increasing responsibility in military matters and in matters relating to the professional work of your rate. When you advance to PO1 or CPO, you will find a noticeable increase in your responsibilities for leadership, supervision, training, working with others, and keeping up with new developments.

As your responsibilities increase, your ability to communicate clearly and effectively must also increase. The simplest and most direct means of communication is a common language. The basic requirement for effective communication is therefore a knowledge of your own language. Use correct language in speaking and in writing. Remember that the basic purpose of all communication is understanding. To lead, supervise, and train others, you must be able to speak and write in such a way that others can understand exactly what you mean.

Leadership and Supervision

As a PO1 or CPO, you will be regarded as a leader and supervisor. Both officers and enlisted personnel will expect you to translate the general orders given by officers into detailed, practical, on-the-job language that can be understood and followed by relatively inexperienced personnel. In dealing with your juniors, it is up to you to see that they perform their jobs correctly. At the same time, you must be able to explain to officers any important problems or needs of enlisted personnel. In all military and professional matters, your responsibilities will extend both upward and downward.

Along with your increased responsibilities, you will also have increased authority. Officers and petty officers have POSITIONAL authority–that is, their authority over others lies in their positions. If your CO is relieved, for example, he no longer has the degree of authority over you that he had while he was your CO, although he still retains the military authority that all seniors have over subordinates. As a PO1, you will have some degree of positional authority; as a CPO, you will have even more. When exercising your authority, remember that it is positional–it is the rate you have, rather than the person you are, that gives you this authority.

A Petty Officer conscientiously and proudly exercises his authority to carry out the responsibilities he is given. He takes a personal interest in the success of both sides of the chain of command. . . authority and responsibility. For it is true that the Petty Officer who does not seek out and accept responsibility, loses his authority and then the responsibility he thinks he deserves. He must be sure, by his example and by his instruction, that the Petty Officers under him also accept responsibility. In short, he must be the leader his title–Petty Officer– says he is.

Training

As a PO1 or CPO, you will have regular and continuing responsibilities for training others. Even if you are lucky enough to have a group of subordinates who are all highly skilled and well trained, you will still find that training is necessary. For example, you will always be responsible for training lower rated personnel for advancement. Also, some of your best workers may be transferred, and inexperienced or poorly trained personnel may be assigned to you. A particular job may call for skills that none of your personnel have. These and similar problems require that you be a training specialist–one who can conduct formal and informal training programs to qualify personnel for advancement, and one who can train individuals and groups in the effective execution of assigned tasks.

In using this training manual, study the information from two points of view. First, what do you yourself need to learn from it? And second, how would you go about teaching this information to others?

Training goes on all the time. Every time a person does a particular piece of work, some learning is taking place. As a supervisor and as a training expert, one of your biggest jobs is to see that your personnel learn the RIGHT things about each job so that they will not form bad work habits. An error that is repeated a few times is well on its way to becoming a bad habit. You will have to learn the difference between oversupervising and not supervising enough. No one can do his best work with a supervisor constantly supervising. On the other hand, you cannot turn an entire job over to an inexperienced person and expect him to do it correctly without any help or supervision.

In training lower rated personnel, emphasize the importance of learning and using correct terminology. A command of the technical languages of your occupational field enables you to receive and convey information accurately and to exchange ideas with others. A person who does not understand the precise meaning of terms used in connection with his work is definitely at a disadvantage when he tries to read official publications relating to his work. He is also at a great disadvantage when he takes the examinations for advancement. To train others in the correct use of technical terms, you will need to be very careful in your own use of words. Use correct terminology and insist that personnel you are supervising use it too.

You will find the Record of Practical Factors, NavTra 1414/1, a useful guide in planning and carrying out training programs. From this record, you can tell which practical factors have been checked off and which ones have not yet been done. Use this information to plan a training program that will fit the needs of the personnel you are training.

On-the-job training is usually controlled through daily and weekly work assignments. When you are working on a tight schedule, you will generally want to assign each person to the part of the job that you know he can do best. In the long run, however, you will gain more by assigning personnel to a variety of jobs so that each person can acquire broad experience. By giving people a chance to do carefully supervised work in areas in which they are relatively inexperienced, you will increase the range of skills of each person and thus improve the flexibility of your working group.

Working with Others

As you advance to PO1 or CPO, you will find that many of your plans and decisions affect a large number of people, some of whom are not even in your own occupational field. It becomes increasingly important, therefore, for you to understand the duties and the responsibilities of personnel in other ratings. Every petty officer in the Navy is a technical specialist in his own field. Learn as much as you can about the work of others, and plan your own work so that it will fit into the overall mission of the organization.

Keeping Up With New Developments

Practically everything in the Navy–policies, procedures, publications, equipment systems–is subject to change and development. As a PO1 or CPO, you must keep yourself informed about changes and new developments that affect you or your work in any way.

Some changes will be called directly to your attention, but others will be harder to find. Try to develop a special kind of alertness for new information. When you hear about anything new in the Navy, find out whether there is any way in which it might affect your work. If so, find out more about it.

SOURCES OF INFORMATION

As a PO1 or CPO, you must have an extensive knowledge of the references to consult for accurate, authoritative, up-to-date information on all subjects related to the military and professional requirements for advancement.

Publications mentioned in this chapter are subject to change or revision from time to time–some at regular intervals, others as the need arises. When using any publication that is subject to revision, make sure that you have the latest edition. When using any publication that is kept current by means of changes, be sure you have a copy in which all official changes have been made.

A list of training manuals and publications that will be helpful as references and for additional study in preparing for advancement is included in the reading list at the beginning of the text. Additional training manuals that are applicable are available through your educational services officer.

In addition to training manuals and publications, training films furnish a valuable source of supplementary information. Films that may be helpful are listed in the U.S. Navy Film Catalog, NavAir 10-1-777.

ADVANCEMENT OPPORTUNITIES FOR PETTY OFFICERS

Making chief is not the end of the line as far as advancement is concerned. Advancement to Senior (E-8) and Master (E-9) Chief, Warrant Officer, and Commissioned Officer are among the opportunities that are available to qualified petty officers. These special paths of advancement are open to personnel who have demonstrated outstanding professional ability, the highest order of leadership and military responsibility, and unquestionable moral integrity.

PROFICIENCY PAY

The determination as to which Navy ratings, NEC's, and Special Duty Assignments are authorized proficiency pay is accomplished through an annual review, within the Bureau of Naval Personnel, of all Navy ratings, NEC's, and Special Duty Assignments. Those ratings, NEC's or special duty assignments which fulfill the Department of Defense criteria for an award of proficiency pay are included in a proposed fiscal year Proficiency Pay Program submitted to the Secretary of Defense for approval.

The Secretary of Defense has authorized two categories of Proficiency Pay for Navy:

1. Shortage Specialty (Proficiency Pay). A monthly amount of pay in addition to any pay and allowances to which otherwise entitled that may be awarded to an eligible enlisted member who possesses a critical rating or NEC. Shortage Specialty (Proficiency Pay) is designed to assist in attaining and sustaining adequate career manning levels in critical ratings and NEC's.
2. Special Duty Assignment (Proficiency Pay). A monthly amount of pay in addition to any pay and allowances to which otherwise entitled that may be awarded to an eligible enlisted member who is assigned to certain special duties. Special Duty Assignment (Proficiency Pay) is designed to assist in attaining and sustaining an adequate volunteer manning level in the critical special duty assignments.

ADVANCEMENT TO SENIOR AND MASTER CHIEF

Chief petty officers may qualify for the advanced grades of Senior and Master Chief which are now provided in the enlisted pay structure. These advanced grades provide for substantial increases in pay, together with increased responsibilities and additional prestige. The requirements for advancement to Senior and Master Chief are subject to change but, in general, include a certain length of time in grade, a certain length of time in the naval service, a recommendation by the commanding officer, and a sufficiently high mark on the Navy-wide examination. The final selection for Senior and Master Chief is made by a regularly convened selection board.

Examination Subjects

Qualifications for advancement to Senior Chief Petty Officer and Master Chief Petty Officer have been developed and published in the Manual of Qualifications for Advancement, NavPers 18068 (Series). They officially establish minimum military and professional qualifications for Senior and Master Petty Chief Officers.

The Bibliography for Advancement Study, NavTra 10052 (Series) contains a list of study references which may be used to study for both military and professional requirements.

The satisfactory completion of the correspondence course titled Military Requirements for Senior and Master Chief Petty Officer, NavTra 91209, is mandatory for advancement to E-8 and E-9.

ADVANCEMENT TO WARRANT AND COMMISSIONED OFFICER

The Warrant Officer program provides opportunity for advancement to warrant rank for E-6 and above enlisted personnel. E-6's, to be eligible, must have passed an E-7 rating exam prior to selection.

The LDO program provides a path of advancement from warrant officer to commissioned officer. LDO's are limited, as are warrants, in their duty, to the broad technical fields associated with their former rating.

If interested in becoming a warrant or commissioned officer, ask your educational services officer for the latest requirements that apply to your particular case.

CHAPTER 2

MANAGEMENT

The AQ in a supervisory position sets in motion the plans, schedules, and policies of his superiors. His primary concern is seeing that the job gets done, rather than performing the work himself.

To accomplish this end, the supervisor must know his men, assign them work within their capabilities, direct their efforts, and assume responsibility for seeing that each job is done correctly.

The supervisor's objectives are to operate with maximum efficiency and safety, to operate with minimum expense and waste, and to operate as much as possible free from interruption and difficulty. These three objectives are amplified in Military Requirements for Petty Officer 1 & C, NavPers 10057 (Series).

It is important that an AQ assigned supervisory duties keep in mind the importance of his new assignment to him personally. It affords him the opportunity to gain practical experience for future promotions. His duties cannot be approached in a haphazard manner. To make right decisions, the supervisor must be knowledgeable, possess integrity, and utilize common sense. He should employ the principles of good leadership in carrying out his assignment. The information provided in Principles and Problems of Naval Leadership, NavPers 15924 (Series), will prove invaluable to the new supervisor until he has gained more experience.

Effective supervision of a work center requires a competent degree of knowledge concerning all areas of maintenance that could affect the work center. The senior petty officer must keep abreast of new ideas and be aware of the variety of directives and publications that regulate his actions. He must be knowledgeable of the factors that make him a maintenance manager, of programs that affect his work area, of his rating, and the weapon system being supported.

The Naval Aviation Maintenance Program (NAMP) OpNav Instruction 4790.2 (Series), outlines command, administrative, and management relationships and establishes policies for the assignment of aviation maintenance tasks.

The supervisor who endeavors to become thoroughly familiar with the contents of the Naval Aviation Maintenance Program Manual, Volumes 1-4, will be better equipped to handle the administrative affairs of the work center. By the time most petty officers reach the E-5 level, they should be totally familiar with the variety of source documents associated with aircraft maintenance. Use of these documents is covered in Military Requirements for Petty Officer 3 & 2, NavPers 10056 (Series). NavPers 10057 (Series), Military Requirements for Petty Officer 1 & C, provides coverage on the various manhour and maintenance data reports as well as other pertinent areas of the NAMP.

The senior AQ will by necessity become involved in the variety of special programs that directly or indirectly affect the supervision of his work center. OpNav Instruction 4790.2 (Series) provides amplifying information on selected maintenance programs such as the following:

1. Component repair.
2. Foreign object damage (FOD) prevention program.
3. Corrosion control and preservation.
4. NavAirSysCom calibration program.

Separate chapters provide in-depth information concerning Quality Assurance, Unsatisfactory Material/Condition (UR) Reporting

System, Planned Maintenance System, etc.

The supervisor who has had varied experience in all aspects of his rating is a definite asset to any command. A complete knowledge on one's rating is not easily achieved. All too often, personnel put in the required training courses and rely on the information retained from the Rate Training Manual to get them by. Study of the latest editions of these manuals and the additional reference material listed in NavTra 10052 will assist in the never-ending attempt to stay current. When advancement in rating qualifications change, the alert petty officer notes these changes and strives to correct any knowledge deficiencies that might exist. Curiosity regarding activity correspondence, changes and bulletins, changes to maintenance publications and other maintenance directives, as well as changes to other information which affects the supervisor's work center and/or rating, can result in increased ability and confidence.

The number of aircraft accidents, ground accidents, and incidents involving human errors has increased steadily for the past several fiscal years. As the number of errors increased, the most often repeated errors continue to be the same from year to year. Some of the errors cause little or no damage and consequently have not been appropriately advertised. Many maintenance errors can be attributed to failure of the supervisor to properly perform his duties.

A knowledge of the weapon system being supported is a must requirement. The training lectures prepared for use in training personnel within the work center should be a valuable source of information regarding the weapon system. Study of the appropriate volumes of the Maintenance Instructions Manual that affect the AQ and completion of courses on the weapons system provided by the NAMTraDet's will better equip the supervisor to make decisions regarding maintenance of the systems. Use of the MIM when performing maintenance applies to both the worker and the supervisor. The complexity of many of today's weapon systems requires that step-by-step procedures be followed for accomplishing removal, installation, repair, operational testing, etc. It is impossible to commit these step-by-step procedures to memory. Personnel who are unfamiliar with a task that is assigned should readily admit their lack of proper training rather than attempt the task with questionable results. It is not uncommon for a supervisor to find that a subordinate has greater knowledge of a particular system than the supervisor. If he has been to one of the NAMTraDet's courses on that particular system and/or has considerable experience, it is entirely conceivable. However, the supervisor must make it a habit to verify any doubtful information and correct any knowledge deficiencies on his part, or he may lose some of the respect necessary to maintain control of his men. This is not to imply that he should be distrustful of his men. Sometimes subordinates feel that information passed on to them by others is correct without verififying it in the MIM's. In summary, it is better to admit when you do not know something and then follow through by doing something about it immediately.

MAINTENANCE MANAGEMENT

Management has been defined as "the efficient attainment of enterprise objectives." Maintenance has been defined as "all actions taken to retain material/equipment in a serviceable condition or to restore it to serviceability." The performance of maintenance requires resources to be available and properly managed at all levels of command. Department of Defense Instruction 4151.12 (Series) has defined equipment maintenance management and stated that the goals to be achieved are those paraphrased below.

"Maintenance management is the process of developing projected workload requirements, planning, organizing, staffing, directing, and controlling the engineering, industrial, and other resources required to achieve the objective. The goals are the effective and economical support of those equipments required to achieve the operational objectives of SecNav and DOD." This definition and its applications are not limited to specified levels of command and must become a part of the maintenance managers daily routines.

The principle of management by exception is fundamental to this entire management system. It means simply that actions or incidents which vary markedly from established standards or norms are singled out as exceptions from the whole for special management attention. For example, if certain models of aircraft or equipment consistently fail to attain established material readiness standards, those models would be singled out for special study and corrective action. Within the aircraft, certain systems or components which are chronically failing and consuming abnormal numbers of maintenance manhours or parts would be exception items. Work centers which consistently fail to meet production schedules or which consistently require overtime work should be singled out for special attention. The principle of management by exception is not new. It is particularly adaptable to aviation maintenance management through the use of modern machine data processing techniques. Supervisors at all levels concerned with maintenance must consciously and intelligently apply this principle in order to most effectively use their resources in men, money, and materials.

The principles of planning, organizing, staffing, directing, and controlling must be understood and implemented if maintenance is to be accomplished in an orderly manner. Although no attempt has been made to list all management principles that may be applicable in individual situations, the requirement for effective application of a few basic principles must be recognized by all maintenance managers. It must also be recognized that mere attention to these principles cannot insure attainment of the desired results. Coordination and communication, both externally and within an activity, are the catalysts which insure the smooth functioning of a maintenance organization; their importance cannot be overemphasized.

SUPERVISION AND LEADERSHIP

The experienced petty officer will soon learn that supervision and leadership are very closely related. The supervisor's role requires that he be a leader, a man of common sense, and a man who earns the respect of others. Many decisions are difficult to make. To be effective in his decision making, the supervisor assembles pertinent facts, policies, and procedures; develops a course of action and evaluates possible alternatives; selects the best course of action; and initiates the required action. When necessary, he consults his own superior prior to taking action. Every supervisor must face problems squarely and make timely and sound decisions. The supervisor who dodges his responsibilities will soon find his control of subordinates slipping away, discipline deteriorating, dissatisfaction with his supervision increasing, and effectiveness of the organization suffering.

The supervisor who establishes and maintains a spirit of cooperation within his work center and in the everyday dealing with other work centers and maintenance control will find his job is much easier. Readiness is the common purpose of the naval organization, and all ratings should share a common interest in achieving that purpose. A willingness by each individual to submerge his personal interests in favor of getting the job done is a necessary prerequisite to cooperation. If the supervisor's requests are reasonable, made well in advance (when possible), were understood, and provided all the necessary information, his requests will generally induce cooperative action. If cooperation is lacking, check the facts to find out why. If subordinates are at fault, they can be told directly and in a firm manner, taking into consideration the basic principles of good leadership.

The supervisor's duties involve planning, direction, and control. Careful planning is an essential ingredient to effective supervision and minimizes other types of supervisory efforts when carefully executed. Time and effort invested in the process of careful planning is rarely wasted. It can result in job simplification and increased efficiency.

The effective supervisor initiates the planning process by identifying each specific job to be done by his men. With a routine clearly established, he can spend his time on the exceptions that may arise. He knows the capacities, interests, weaknesses, and potentials of his men. Knowing each man's level of technical skill, motivation, ambitions, and personality characteristics will enable the supervisor to (1) assign the right man to the right job, (2) identify the training needed by each man to do a better job, and (3) establish the standard at which each man can be expected to perform.

Once action has been initiated, the supervisor provides direction. This function of supervision is like that of a "foreman." He sees that work is started and knows what is going on at all times. This does not mean that he must always be physically present while the job is being done. Subordinates should be trained to assume responsibility for the job in the absence of the supervisor so that no man is indispensable, including the supervisor. The supervisor should, however, be available when his men are working, and they should know how to contact him. The supervisor should always be present when his men are assigned new tasks, when they have trouble getting a job done, or when other circumstances dictate the necessity for his presence. He must be careful not to oversupervise lest he destroy the initiative of his workers and subordinate supervisors. He receives suggestions and reactions from his subordinates and acts as necessary on them, giving credit when and where it is due. Recognition of each man as an individual is required.

Control of a job refers to the function of checking to see that the job is done as planned—a comparing of performance with plans. Deviations may reflect poor planning. However, procedures should exist whereby changes in plans that could result in improved performance can be implemented to minimize repetition of faulty performance.

The supervisor will be challenged to allocate sufficient time to be expended on planning, direction, and control. A spirit of firmness, fairness, cooperation, decisiveness, harmony, and mutual respect while seeing that the job is done will rarely go unrewarded.

Communications

The area of communications as related to supervision and leadership is singled out here because of its importance. Almost without exception, problem areas regardless of their nature can be attributed to the lack of proper communications. Men like to be kept informed about all the things that affect them. Keeping them informed will improve their morale and generally make them more responsive to the needs of the command. The supervisor can improve morale by keeping his men as well informed concerning need-to-know and nice-to-know information that could affect them.

Communications is a two-way process. The supervisor must be able to convey his ideas, orders, etc., and pass on information, either orally or in writing, in such a manner that it will be clearly understood. He must also be willing to listen to and try to understand the ideas of others. Subjectivity (that is, looking at things only from a personal viewpoint, because of your position, rating, pay grade, or any other reason) will hinder communications. Bias and limited knowledge can limit a supervisor's ability to be objective, and by recognizing this fact he can listen more objectively.

Ridicule. sarcasm, vulgarity, etc., have no place in good communications. The supervisor who must get loud and resort to such language to get his point across or the job done needs to realize how adversely such action affects his own feelings of importance and respect. When it becomes necessary to orally reprimand a subordinate, do it in private, keeping in mind that he is an individual and as a petty officer he must have the respect of the men under him. If a supervisor reprimands a man in public, both lose respect and are less effective in getting the job done.

Professionalism

It is the responsibility of all senior petty officers to instill a spirit of professionalism in their subordinates. Aircraft maintenance is a reasonably complicated profession that leaves little room for error. The AQ who gives it less than his undivided attention presents a potential hazard.

The responsible petty officer sets the example he wishes others to follow, doing the right thing in carrying out each assignment, including (and especially so) when no one is watching. Undiluted professionalism means that there is no room for ethical lapses or occasional breaches of integrity. The worker who even once shortcuts established procedures, does not follow mandatory instructions, generally sacrifices quality for speed, or performs any other action which could produce a negative judgment towards him lacks the professional integrity demanded in aviation maintenance. The supervisor who condones such action is equally guilty of a less than professional attitude and the results that such actions could cause.

There is no substitute for thorough knowledge of your aircraft, your job, and the procedures associated therewith. Correct maintenance procedures and thorough quality assurance will almost always produce professional results. Aviation safety demands pure, undiluted professionalism from all personnel involved in maintenance.

SCHEDULING

A supervisor should include known future assignments in the work schedule. If it is known that on a certain date certain jobs must be performed, the work schedule can be arranged so that routine work will have already been accomplished

One of the most important aids in supervision is a job plan. When setting up a job plan, consider these questions:

1. What is the job?
2. How can it be accomplished?
3. How many men are required?
4. What tools and materials are necessary?

Determining which jobs should be performed first will be one of your major responsibilities. This is an important phase of your work for these decisions determine the use of your facilities–men, material, and machinery. Routine work presents no particular problem to a well-organized shop. However, rush jobs can cause confusion unless you have already thought them through and taken steps to see that the work follows well-founded principles.

When scheduling work, insure (if practical) that the men or crews will be working on different types of jobs. If a number of men or crews are assigned to the same type jobs there may be an overdemand for certain test equipment, tools, and workspace. This often results in confusion and loss of time.

It is also important to schedule activities so that work is accomplished in the proper sequence. This is especially important if you have men working on different phases of the same job.

Future job assignments should be included in the work schedule so that time will be allotted to accomplish them. This may make it necessary to rearrange the present work schedule to insure that special jobs will not interfere with the accomplishment of routine work.

CHECKING PROGRESS AND EVALUATING PROCEDURES

The assignment of work is only the first step in processing a job. The AQ who is in charge must know his men. He should have a fairly good idea of each man's skill and ability, as well as each man's knowledge regarding the operation of equipment and the accomplishment of repair work.

The best way in which the AQ supervisor can obtain this knowledge is to make frequent inspections and check the progress of work being performed. In that way, he will have a good idea as to which jobs, or which men, will require the most supervising.

When checking on the progress of work, the senior AQ should be sure that the men are observing proper safety precautions in regard to themselves and the equipment they are operating. In addition, he should see that each man is using the proper tools, and note the quality of work being performed.

In case of any doubt, the supervisor should check to see that the men understand his instructions properly and are doing the work correctly. If necessary, he should provide additional instructions to give a better understanding of the job, or to improve workmanship. By frequently talking to the men and answering their questions, the supervisor can prevent work and material from being wasted, as could be the case if he were not available to give the correct details.

QUALITY ASSURANCE

All work completed is subject to inspection by the crew supervisor and quality assurance inspector. The inspection is performed to aid in the reduction of human error and to insure that all material used was of the proper type and quantity. Quality assurance inspections are not used to replace the responsibility of the crew leader or supervisor but to enhance the reliability of a weapon or weapon system.

Generating quality in an organization necessitates a sincere interest on the part of commanding officers, plainly evidenced to the officers and men in their commands. Quality further requires that each officer and supervisor understand clearly how the accomplishment of a quality job contributes to the effective operation of the organization. Quality also requires that each worker understands not only a set of specification limits, but also the intent and the need for these requirements.

The quality assurance organization is concerned with three functional areas–quality management, quality verification, and technical publications.

Quality management is monitored by formulating, implementing, and auditing procedures, instructions, and operations to assure compliance with the policies stated or implied within the NAMP Manual. Quality assurance coordinates their efforts with those of the activity's data analysis group to provide information on maintenance practices and results based on facts gleaned from the various maintenance source documents and associated reports.

Quality verification assures that all materials processed and actions taken by all personnel meet prescribed quality requirements. Direct inspection of material and operations as they are performed is necessary on a continuing basis to give adequate assurance that all items processed and tasks completed meet the prescribed requirements. These quality assurance considerations (tests, inspection, etc.) are included in most weapon system Maintenance Requirements Card decks as well as most Maintenance Instructions Manuals, and Overhaul and Repair Manuals. Quality assurance verification steps are generally called for at various steps during repair progress in addition to verification of the final product.

Inspectors

Personnel to be designated as inspectors should possess the following attributes:

1. Should be experienced and fully knowledgeable within his technical rating.
2. Should possess the ability to research, read, and interpret drawings, schematics, technical manuals, and directives.
3. Should be able to write with clarity and technical accuracy.
4. Should be observant, alert, and inquiring with a record of excellence and stability in the performance of his duties.
5. Should be able to work with others and possess the personal desire and motivation to develop a greater knowledge of his technical speciality.
6. Should be senior in his paygrade and experienced.

Each man designated as an inspector should receive an indoctrination on quality assurance objectives, policies, and procedures as provided in OpNav Instruction 4790.2 (Series). The indoctrination requirement is directed toward developing an appreciation for the importance and necessity of an organized quality assurance effort on a continuing basis.

Training of Inspectors

Training of personnel involved in quality assurance and collateral duty inspection requires continuous training in weapon system familiarization, repair procedures, troubleshooting techniques, inspection, testing, and quality assurance considerations specifically applicable to their areas of maintenance.

Quality assurance representatives verify the adequacy and accuracy of inspections performed by the collateral duty inspectors of the work center. Collateral duty inspectors are permanently assigned to the work center and, in addition to other assigned duties, they are assigned to inspect work accomplished by other personnel within the work center. Both the representatives and the inspectors are designated in writing by the commanding officer. Only those personnel designated in writing are authorized to sign as inspectors on maintenance forms or to certify in any way that a component or equipment is ready for issue or use. A sample inspector designation form is provided in OpNav Instruction 4790.2. Copies of the form are kept in the quality assurance files and the division officer's files, with the original going in the man's service record.

Aircraft Squadron Quality Assurance

Since technical information has a direct relationship towards assuring the quality of work performed, the quality assurance division of an aircraft squadron has the responsibility of operating a master technical library and monitoring of dispersed libraries within the various work centers. Dispersed libraries located within the work centers are necessary to place technical information in the hands of the user who is charged with compliance. The quality assurance division monitors the operation of these dispersed libraries, providing new publications, revisions, cancellations, and such other information that may affect the publications held. A change entry certification form is utilized to insure that all change and revision material is entered into the directives and manuals of the dispersed libraries within a reasonable time.

Quality assurance functions previously discussed in this section are also applicable to AQ's in an aircraft squadron.

Quality Assurance Audits

An audit plan that encompasses all areas of work performed in the maintenance department is developed by the quality assurance officer and is utilized to audit each work center at least once quarterly. The audit plan is designed to evaluate the adequacy of technical documents, the quality of work being performed, and the validity of related maintenance and quality assurance inspection procedures.

Internally caused deficiencies are reported to the appropriate supervisor with requirements for corrective action.

Externally caused deficiencies are discussed with the work center concerned and a complete report is submitted to the maintenance officer with comments and recommendations for remedial or corrective action as required.

BRANCH MANAGEMENT

Management at the work center branch level is normally supervised by the senior AQ assigned. The supervisor has many responsibilities associated with personnel, material, and combat readiness to carry out. With proper leadership and attention to detail, the supervisor can instill the driving power in his subordinates to meet the commitments of his command. Some of the responsibilities of a supervisor at the branch level (or any crew) include the following:

1. Accomplishment of all assigned work.
2. Maximum utilization of personnel and facilities.
3. Recommending the repair capabilities and facilities of the work center to the higher echelon.
4. Inspection of all completed work when required.
5. Initiating material requirements to support the present and projected work center requirements.
6. Completing and forwarding all required reports.
7. Maintaining records as required.
8. Coordination of the work center tasks through maintenance control.
9. Organization and control of the work center training program to support the department and command training program.
10. Monitoring the NAMP documents for completeness, accuracy, and timely submission.
11. Recommending necessary changes in methods and techniques to promote maximum safety, material readiness, and combat readiness.

Zero Defects

The "Zero Defects Program" was developed by the Navy for a continuing effort to improve the overall work efficiency of equipment and personnel. The goal of the program is applicable to all activities (and supervisors) concerned with the production, maintenance, and handling of aeronautical equipment.

The supervisor at the lowest level, up to and including the CNO, is responsible for reducing the incidences of error caused by lack of proper training, facilities, equipment, procedural methods, quality assurance, control programs, and motivational concern.

The concept of the program is to complement other motivational effort programs including the following:

1. Cost reduction.
2. Beneficial suggestions.
3. Incentive awards.
4. Value engineering.
5. Quality assurance.
6. Aviation safety.

Commanding officers and officers in charge are responsible for implementing the zero defects program and designating a qualified officer as coordinator. The quality assurance officer normally performs this function at the organizational and intermediate levels. The work center supervisor, under the guidance of the program coordinator, will control and direct at the work center level to achieve zero defects on all tasks completed by his crew.

The loss of lives due to human error can be vastly reduced by each man performing at his best on all tasks assigned. The crew leader, supervisor, and quality assurance inspectors are used to check completed work to provide a check system against "Murphy" type errors, improper performance, and oversights. The goal of the zero defects program can be accomplished only with each man taking pride in his accomplishments and striving to learn more, never resting on past accomplishments.

Work Simplification

Work simplification is a common sense, systematic method of identifying and analyzing work problems, developing solutions, and installing improvements. In order to achieve maximum efficiency each supervisor must do his part to improve the work situation and achieve maximum manpower utilization. This implies that the greatest possible use of all resources available be made in order to help accomplish an activity's mission. Work simplification is a tool which can be utilized effectively in the accomplishment of this goal. Work simplification might be considered as human ingenuity applied to the work situation. It is the organized use of common sense and creative thinking in the solution of work problems.

If all men had believed that there could be no better way of doing things, we might still be throwing rocks at game for our food and traveling from place to place on foot. Progress in these fields was not made in a single step but in a series of improvements. These changes occurred slowly over the centuries, growing out of a multitude of small improvements.

The supervisor who lives day to day, satisfied that what he did yesterday is good enough for tomorrow, will, in most cases, leave his job no better from having held it. He leaves nothing significant for other personnel to follow him in his job, and he becomes lost in the shuffle of men who are content with merely living and dying.

The majority of improvements in our world did not come by accident; rather, they came as a result of man's ingenuity, growing out of his sense of imperfection and his constant search for improvement. When an improvement is made, no matter how small, it marks its discoverer as a person of imagination with a real and active interest in his work.

The supervisor who believes in and practices work simplification procedures can look with pride upon his contributions or those of people who work with him. This means that the supervisor should never cease to search for improvement and must encourage his workers to try to improve jobs over which he has control.

The supervisor should always watch for areas where work can be simplified. Work simplification pays immediate dividends by increasing both production quality and quantity. It allows the supervisor to meet work schedules more easily and reduces waste by producing with less effort, increases savings in time and manhours, and thus reduces cost of operation. Work methods improvement aids in establishing standard procedures. These standard procedures aid in training both old and new workers, since most workers are easier to train, and learning is much easier if standard practices are used.

An example of work simplification that is widely used in maintenance activities is a reports tickler file. The tickler file contains information on each report concerning the kind of report required, form or format to be used, due date, address of the office or command to which it is sent, etc. Although the governing directive should be consulted when preparing a report, a properly used reports tickler file simplifies and assists in the preparation and timely submission of required reports.

Work simplification should be considered when arranging the shop equipment (intermediate maintenance) in the work center. Equipment should be located so that ample room is available to accommodate its use. When possible, equipment should be arranged in a logical manner so that jobs requiring the utilization of several items of equipment can be used in a manner similar to that found in assembly line operations. In a like manner, visual information display boards and/or status boards utilized to control maintenance should be located where they can be easily viewed and kept current without disrupting other personnel.

It is true that with good leadership personnel can be encouraged to work to the limit of their physical endurance but unless their efforts are used wisely, the most critical resource—manpower—is being wasted. In the final analysis, it is not how hard personnel work but how much quality work is accomplished that matters. Therefore, to help achieve maximum results with minimum expenditure of human effort, the supervisor should always strive to use established work simplification techniques.

Work simplification permits continuous evaluation by analyzing existing methods and procedures with a view toward improving them. There is always a better way of performing a task by using streamlined methods, improved tools, better working conditions, or shorter procedures. However, these better methods are not always apparent. Work simplification should be directed at all work situations where physical effort is expended.

TECHNIQUES.—There are many techniques for improving work methods. For the most part, these techniques are adaptable to any work center or production control as well as the whole activity. Five of the principal techniques which have been successfully applied to work operations are discussed briefly.

Work Distribution Analysis.—Work distribution analysis is a technique used to analyze objectively the division of work in an organization. In order to obtain the most effective distribution of work, it is necessary for the supervisor to have an overall view of the organization and its operations. The supervisor must clearly understand the work that is being done and be able to see the relationship between the overall operation and the individual work units as well as the contribution that each person makes to the work of the whole organization.

Distribution of work is an important factor in efficient use of manpower. Time and effort are saved if related duties are performed by the same person. Thoughtful matching of assignments and qualifications is important so that personnel are not struggling with work that is too hard for them or wasting their time on tasks that might be performed by a less skilled person. Another consideration is distribution of workload to avoid inequalities, since these result in bottlenecks and other inefficiencies.

Work distribution analysis requires that a Task List be completed for each person whose work is being studied. This list contains, in simple statements, tasks the worker performs regularly and the average number of hours spent on each task per week. Next, a Function List is prepared which lists each function performed by the work center. Each task reported on the Task List must be related to a specific function. A Work Distribution Chart is prepared from the data collected on the Task List and Function List. This chart presents the work performed in the existing organization under current operating conditions. The chart is then studied and analyzed to find answers to questions such as the following:

1. What functions take the most time?
2. Is there misdirected effort?
3. Are skills being used properly?
4. Are personnel doing too many unrelated tasks?
5. Are tasks spread too thinly?
6. Is work distributed evenly?

A careful study and analysis of the work distribution chart should assist in achieving the following results:

1. Elimination of unnecessary tasks.
2. Reduction of time spent on relatively unimportant functions.
3. Elimination of duplication and overlapping of work.
4. Better balance of workloads.
5. Combination of related tasks.
6. Realistic estimate of personnel needs.
7. Better utilization of skills.
8. Reallocation of misassigned personnel.

Work Count Analysis.—Work count analysis supplements the work distribution analysis and is a technique for determining the volume of work in terms of measurable units. Information obtained by counting or measuring the work provides a basis for improving methods and procedures, adjusting work assignments, evaluating performance, and eliminating bottlenecks. Such information is useful in assigning and scheduling work to insure that the workload is equitably distributed among all personnel.

Items of work counted should be definite and comparable. Items counted should also be representative of work usually performed. Only those should be counted that clarify methods employed. Counting may take place where the work is received, where a decision is made or action is taken, where a process is completed, or where long storage occurs.

Work count information can be used to accomplish the following:

1. Establish how long it takes to do a given piece of work.
2. Indicate whether the volume of a certain piece of work is sufficient to warrant specialization.
3. Show whether work is distributed evenly among workers.
4. Point out bottlenecks where work piles up.
5. Indicate whether the work center is adequately manned, overmanned, or undermanned.
6. Stimulate interest of personnel by providing comparisons of one person's work with that of another or with his own record during a different counting period.

Flow Process Analysis.—Flow process analysis is a technique for analyzing flow and sequence of operations. The purpose of this analysis is to reduce time and distances in a process by eliminating, combining, and changing the sequence of steps in the flow of work.

The principal tool of this technique is the construction of a flow process chart which provides a clear and detailed picture of the flow of work. Recording each step in a procedure helps to identify duplication of effort, backtracking, and other obstacles to the smooth, efficient flow of work.

Motion Analysis.—Motion analysis is a technique for making maximum use of physical motions. It is a method of studying the motions of individuals in performing their various tasks.

Work distribution and flow process analyses are directed toward improving the division and flow of work. Motion analysis deals with how an individual performs his tasks. It seeks to learn whether the workers are doing their work with minimum fatigue, loss of time, and waste of effort. Improvements are effected by rearrangement of materials and work area and by proper use of equipment.

The simplest way of gathering data for motion analysis is for the supervisor to watch his personnel at work and note useless motions. Motion analysis should result in the elimination of wasteful motions and consequent loss of work time, reduction of fatigue by lessening the amount of physical effort required to complete a task, and increase the efficiency of personnel.

Layout Analysis.—Layout analysis is a procedure designed to lead to better utilization of space, personnel, and equipment. A study of the layout of a working area can provide useful information for improving the work of individuals, distribution of the workload, and flow of work from one person to another. Its purpose is to determine what space is needed for the operations to be performed and how the available space may be used most effectively. Besides shortening and simplifying motions, it should produce working conditions that are as comfortable and personally satisfactory to the workers as possible consistent with efficient and economical operation.

The layout chart is the principal tool of this type of analysis. This chart consists of a floor plan of the work space, showing doors, windows, electrical outlets, etc. All features that restrict usable space should be included. Items of projected new equipment should be added and the anticipated flow of work indicated.

WORK CENTER ORGANIZATION

The average Chief or First Class Aviation Fire Control Technician may never have the opportunity to plan the organization of an avionics shop in a new facility. In most cases he will take charge of an already functioning work center or, when his squadron or unit deploys or moves to a new base, he and his crew are usually assigned to spaces already basically equipped. In either case, a reevaluation of the work center's layout is indicated.

WORK CENTER LAYOUT

The reevaluation of the layout should include determining, from the applicable allowance lists, if the equipment allowances have changed in any way. There is no use relocating equipment which involves rewiring or plumbing work if improved replacement models are authorized and available.

A basic consideration in planning a work center layout is its purpose. When more than one space is available, the supervisor must decide which will most nearly fill the requirements of space, ventilation, lighting, and the distance from flight line and hangar. This decision should be based on factors of safety, economy, functional compatibility, and convenience.

Equipment Arrangement

The arrangement of the work center equipment should be made on the basis of utility rather than appearance. Moving an item of equipment into an out-of-the-way corner may greatly improve the appearance of the work center but at the same time reduce the efficiency of personnel using the equipment and may possibly create a safety hazard. A good rule to follow is to locate equipment where it can be safely used by the greatest number of people with a minimum of effort in the least amount of time.

Work tables and benches should be positioned with respect to fixed equipment so that the equipment most often used is most quickly and easily reached. Electrical and compressed air outlets should be readily available to the workbenches. Needless delays are caused by having to rig unnecessarily long connections from poorly located outlets.

Near workbenches where specific and intricate maintenance functions are performed, consideration should be given to installing special lighting such as explosion-proof, vapor-proof, or interference-free type lighting. Under certain conditions, special lighting may also include floodlights for outside work areas and in hangars when improved lighting is required.

Utilization of paint in various colors to emphasize portions of intricate machinery for safety and reflective purposes is known as dynamic painting. Painting in this category should not be utilized for normal building maintenance.

A system of stowing tools must be devised. An intelligent system cannot be set up without first determining from allowance lists what tools will be required for satisfactory operation of the work center. The place for all tools should be marked or otherwise specified, and everything not being used should be kept in that place.

The layout should make provisions for a bulletin board upon which may be posted safety posters, maintenance posters, instructions and notices, plans-of-the-day, and such other information as is appropriate from time to time. The bulletin board should be located in a prominent place in the work center, preferably near the entrance where everyone assigned will have to pass at some time during the day. Material on the bulletin board should be changed frequently, expired notices promptly removed, the current plan-of-the-day posted early, and other posters and material rotated periodically. If the same material is presented in the same format every day, it will not be long before the men begin to ignore the bulletin board and purposes for having it are defeated. New arrangements are noticed and interest is stimulated with variety.

When aviation organizational level maintenance activities are moved aboard ship, their working conditions and accommodations are drastically affected. The ingenuity of the supervisor will be required to produce a workable arrangement within very limited spaces. Stowage racks for toolboxes and other work center equipment should be located to accommodate their frequency of use. Some equipment used at less frequent intervals may have to be stowed in voids. An inventory listing of such items, showing their specific location, will be necessary. Security of material stowed in voids, toolboxes, and other equipment will require more attention than when ashore. Gear not properly stowed and afforded appropriate security has a habit of disappearing, and during rough sea states, can be hazardous to personnel and/or other equipment.

Much of the work done aboard ship will have to be done under less than ideal conditions. Confined spaces, reduced lighting during nighttime flight operations, hazardous conditions on the flight and hangar decks, problems associated with respotting of aircraft to accommodate maintenance, and a variety of conditions peculiar to ship operations will require modification of procedures used ashore. The supervisor should insure that spaces are utilized to their fullest extent.

Since most organizational level maintenance is "on aircraft" type maintenance, the limited space of the work center should present only a minor problem concerning the stowage of gear and some personnel congestion during periods when personnel are awaiting work. Consideration of the factors previously discussed under "Work Simplification," and further discussed in NavPers 18359 (Series), could result in a smoother transition from shore to shipboard facilities and vice versa.

Shared Spaces

It may be necessary to share a working space with another squadron or unit while deployed to an advanced base or aboard ship. Other than having less area to work and store equipment in, this should present no major problem if an intelligent arrangement is worked out with your corresponding member in the other unit.

Consideration must be given to each squadron's mission if different types of aircraft are involved. Friction between units can be avoided if the details of cleanliness, upkeep of spaces, and security are equitably worked out and a schedule posted.

STOWAGE OF CRUISE BOXES AND LOOSE EQUIPMENT

The stowage of cruise boxes and loose equipment is necessary whether deployed or at home base. They should be stored in a dry and secure space when not in use.

Cruise boxes are usually of the type which will collapse and fold when not in use and may be stacked to conserve space. Aboard ship they must be securely tied down to prevent them from shifting in heavy weather.

UTILIZATION OF SHIPBOARD STOWAGE AREAS.—Aboard ship space to store equipment is always at a premium. Items which are frequently used should be stowed in the most accessible spaces while those which are bulky or seldom used should be stowed in the more inaccessible areas. Flammable or explosive items must never be stowed in other than approved spaces. (Check with the ship's fire marshal for approval.)

PERSONNEL MANAGEMENT

One of the problems that a supervisor will encounter is that of personnel management. The supervisor must realize the importance of long range planning to insure that his personnel are trained and available to complete scheduled deployments.

To assist the operating activities in their personnel management, a Manpower Authorizations, OpNav Form 1000/2, is furnished each activity listing by pay grade and NEC the number of personnel authorized. The authorized manpower is the result of extensive study by NavAirSysCom; it is based on the weapons system, the type of operations being conducted, and the recommendations of the supplying contractor.

It is the responsibility of the supervisor to compare both the number and grade of personnel and their NEC's with the authorizations. Any variation in the two should be reported to the department/division officer as appropriate with recommendations based on facts.

If the manpower authorizations differ (in number, pay grade, or NEC) from actual requirements of the organization and this difference cannot be corrected by training, this should be reported to the department/division officer. A Manpower Authorization Change Request, OpNav Form 1000.4A, should be initiated to request appropriate changes. OpNav Instruction 1000.16 (Series) provides instructions for preparation of Manpower Authorization Change Requests.

A document which the supervisor should utilize in the management of personnel is the Enlisted Distribution and Verification Report (BuPers 1080-14). This monthly report, which is normally maintained in the Enlisted Personnel Office, contains a multitude of information such as expiration of enlistment, time in service, NEC codes, and projected rotation month. For those activities classified as shore duty, the projected rotation date reflects the month and year a man is to be transferred; for sea duty activities, the report indicates the month and year that the man's sea duty commenced.

Personnel who have been ordered to report for duty are also covered by the report.

Utilization of this report by the AQ supervisor permits long range personnel planning for school quotas, leave, and rotation of billets within the division.

SAFETY

The Chief of Naval Operations at the direction of the Secretary of the Navy is assigned the responsibility for implementation, direction, and supervision of the Department of the Navy Safety Program. This assignment was made to coordinate the effort and provide positive overall supervision through the chain of command. In this respect, safety becomes an inherent responsibility of command. Command implementation comprises those functions associated with command in carrying out safety policies and directives, and in amplifying safety guidance where necessary. The objective of the safety program is to establish an effective, aggressive, and continuous accident prevention program with the goal of enhancing operational readiness by reducing deaths and injuries to personnel as well as losses and damage to all Navy material from accidental causes.

AVIATION SAFETY PROGRAM

The activity safety officer is required to provide safety education throughout the command as well as to insure that safety standards and procedures are incorporated into all activity functions. Other equally important tasks include translating data concerning accidents and mishaps into useful and meaningful information for activity use, monitoring the existing environment for hazard potential, and keeping the activity advised in matters concerning safety and accident free operations.

The key to this program as with many other programs is effective communications at all levels of command. A variety of publications are afforded to the safety officer and key members in the safety program. The Naval Safety Center helps to promote safety in aviation and other areas of operations through various safety oriented publications. Most of the publications are automatically distributed to aviation squadrons, ships, staffs, and shore activities. Each publication is intended for a primary audience but, in general, can be useful source material for a complete safety program. A brief introduction to these publications is provided in the following paragraphs.

APPROACH MAGAZINE, the Naval Aviation Safety Review, is published monthly for the benefit of all levels of naval aviation. It contains articles on flight operations, flight surgeons' notes, maintenance commentaries, and short features with the purpose of presenting the most accurate information currently available on the subject of aviation accident prevention.

MECH, the Naval Aviation Maintenance Safety Review, is published quarterly and is directed at the enlisted aviation maintenance personnel. It presents the most accurage information available on maintenance-caused mishap prevention and general aviation ground safety directed at reducing maintenance errors and handling mishaps. Contents of MECH are intended to be informational and should not be considered as orders, regulations, or directives.

CROSSFEED, Cockpit and General, is a monthly newsletter which provides a medium through which the experiences of operators of specific aircraft can be shared with others who operate the same type aircraft. The Cockpit Crossfeed is directed at the commanding officer, pilots, and crewmembers of specific aircraft. It contains sections prepared by aircraft analysts for types of aircraft based on selected accident, incident, and ground mishaps as well as accident rate tables. General Crossfeed is directed at maintenance managers and personnel concerned with specific aircraft. It contains articles directed toward the solution of maintenance problems for these particular aircraft, sections on specific maintenance areas, personal/survival equipment, facilities, accident investigation, and Naval Air Training and Operations Standardization (NATOPS) status reports.

WEEKLY SUMMARY OF MAJOR AIRCRAFT ACCIDENTS contains safety discussions, accident briefs, statistics, and safety tips. It is provided primarily for command considerations.

SHIPS SAFETY BULLETIN is a monthly publication and is the counterpart of the Weekly

Summary of Major Aircraft Accidents. It contains articles on current shipboard safety problems, trends, accident briefs, and statistics pertaining to ships safety.

The Safety Center also provides posters featuring the various aspects of operations at sea, in aviation, and ashore. They are available on request from the NavSafCen. Articles for these publications are submitted by fleet activities and training commands. Personnel with safety related experiences that might benefit others should pass it along to the safety center for consideration. Most of these publications are intended for more than one reader, and the information contained in them should be appropriately disseminated.

The safety program established at the maintenance department/division level must be a primary concern of all hands. It requires active participation by all personnel on a day-to-day basis to obtain the desired results. The quality assurance division is assigned overall responsibility for the safety program at this level and establishes a coordinating group to assist in implementing the total safety plan of the activity. The quality assurance plan for the activity includes the safety program requirements. Lower level directives are prepared as necessary to insure proper implementation throughout the department/division. Items given attention in the maintenance safety program include, but are not limited to, the following:

1. Dissemination of appropriate safety posters and literature.
2. Reporting of all accidents, incidents, and unsafe practices in the department.
3. Conducting of safety meetings within the department/division. The minutes of these meetings and pertinent agenda items should be published and made available to the maintenance supervisors concerned.
4. Participation in activity safety surveys as may be required by higher authority. Safety Review Checklists are available from the Naval Safety Center as an aid for conducting safety surveys.

Effectiveness and safety result from properly trained personnel using properly designed equipment in accordance with established procedures under competent and persistent supervision.

Aircraft maintenance is to some extent, naturally hazardous due to the nature of the work, the equipment involved, and the sensitivity of ammunition and pyrotechnics. Factors which can function to increase or decrease these hazards include the following:

1. The experience levels and mental attitudes of assigned personnel.
2. Tempo of operations combined with haste and inattentiveness.
3. Unnecessary risk or disregard of common safety practices.
4. Disregard or unawareness of technical and safety directives.
5. The quality or lack of supervision of the maintenance tasks.
6. The adequacy of indoctrination of all personnel regarding the potential hazards within the work area.

The primary function of AQ's is that of keeping assigned aircraft in top operating condition and to achieve a high degree of readiness for prompt and sustained combat operations.

Accident prevention is affected more by the quality of professional competence demonstrated by key individuals than by any other consideration. The close personal attention of maintenance supervisors is required.

The concept of aircraft maintenance safety should extend beyond concern for injury to personnel and damage to equipment and aircraft. Safe work habits go hand-in-hand with flying safety. Tools left in aircraft, improper torquing of fasteners, and poor housekeeping around aircraft can cause conditions which may claim the lives of flying personnel as well as cause strike damage to aircraft. Safety on the ground is equally as important as safety in the air.

A recent type commander letter states in part, "While the increased complexity of our modern aircraft is a factor, it is noted that a large number of maintenance-error-cause accidents and incidents are due, not to complexity of equipment, but to lack of supervision and technical knowledge. Many mistakes are simple ones in routine maintenance."

Safety in aircraft maintenance depends largely upon the supervisory personnel. The standards of quality which they establish are directly reflected in the quality of the aircraft maintenance. The primary duty of the senior petty officers is to supervise and instruct others rather than to become totally engrossed in actual production. Attempts to perform both functions invariably result in inadequate supervision and greater chance of error. Supervisors must exercise mature judgment when assigning personnel to maintenance jobs. Consideration must be given to each man's experience, training, and ability.

Sometimes overlooked in a maintenance program are the considerations generally grouped under the term "human factors." These factors are important in that they determine if an individual is ready and physically able to do work safely and with quality. Supervisory personnel should be constantly aware of conditions such as general health, physical and mental fatigue, unit and individual morale, training and experience levels of personnel, and other conditions which can contribute in varying degrees to unsafe work. Not only is it important that proper tools and protective clothing and equipment are available for use, but also the insistence by maintenance supervisors that they are used is of increasing importance with modern high performance aircraft. For example, maintenance personnel are sometimes negligent in the wearing of protective hearing devices in high noise areas.

Technical knowledge also plays a large part in a good maintenance safety program. The complexity of our modern equipment demands the attention of well-informed and expert maintenance personnel; otherwise, our weapons systems cannot be operated and maintained. Technical knowledge is a function of education and training which, incidentally, does not end with graduation from Class A school. Graduation is only the beginning. Any AQ worthy of the rating is continually training and learning through self-study and application and through a personal desire for proficiency and self-betterment. But technical knowledge by itself is not sufficient unless it is coupled with an old-fashioned craftmanship that receives gratification and keen satisfaction in doing any job well. The AQ who wished to contribute to safety and reliability improvement must know his job and must develop professional pride in the quality of his work.

It is a continuing duty of every person connected with aircraft maintenance to try to discover and eliminate unsafe work practices. Accidents which are caused by such practices may not take place until a much later date and their severity cannot be predicted. The consequences may range from simple material failure to a major accident resulting in serious injuries or fatalities.

There are several areas in which the supervisor can effectively work to minimize accidents. The organization and administration of an active and continuous program of accident prevention with provisions for inspection of work areas, tools, and equipment; correct interpretation and dissemination of safety directives and precautions; and energetic and imaginative enforcement of them are all important.

ORGANIZATION AND ADMINISTRATION OF AN ACTIVE PROGRAM

It is the responsibility of all supervisory personnel to insure that their subordinates are instructed in and carry out the applicable safety precautions for their area of work. Each individual is held responsible for knowing, understanding, and observing all safety precautions applicable to their work and work areas. The individual is additionally charged with the following responsibilities:

1. The individual should report to work reasonably rested and emotionally prepared to perform the tasks at hand.
2. He should exercise normal prudence in all his functions, commensurate with the work at hand.
3. He should report all unsafe conditions regarding equipment and materials and any unusual or developing hazards to his immediate supervisor for appropriate action.
4. He should warn others whom he believes to be endangered by known or potential hazards and of their failure to observe safety precautions.
5. He should report to his supervisor any accident, incident, injury, or evidence of potential hazard occurring in the course of work.
6. He should wear or use the protective clothing and/or equipment of the type ap-

proved, required, and provided for the safe performance of his work.

7. He should report for work suitably attired for his assigned tasks. For example, wear eye correction, hearing aid, foot protection, style of clothing, hair style, beard, etc., as applicable, that would not present a hazard.

The safety program must be in accordance with local instructions and instructions provided in OpNav Instruction 4790.2 for the maintenance department/division safety program. The Navy Aircraft Accident, Incident, and Ground Accident Reporting Procedures provided in OpNav Instruction 3750.6 (Series) require maintenance personnel participation in investigating, reporting, and preventing aircraft accidents/incidents.

NavMat Publication P-5100, Safety Precautions for Shore Activities, contains precautions that cover almost all aspects of maintenance safety that are to be implemented by maintenance personnel. Mandatory precautions in this manual are characterized by use of the words shall, must, and prohibited. Recommended or advisory precautions are indicated by use of the words should, will, and may. The precautions are of necessity basic and general in nature and are not inclusive of all conceivable operations and functions involved in the large variety of Navy day-to-day activities. Reference is made from time to time to other publications for detailed safety information applicable to a specific condition or hazard. Lack of documented hazards is not an indication of their nonexistence or unimportance. Maintenance personnel must display continuous cooperation and vigilance in seeing that all operating procedures and work methods do not unnecessarily expose personnel to injury or property to loss or damage.

The NATOPS program provides complete and detailed guidance on procedures and precautions to be followed when operating naval aircraft. General guidance of concern to supervising petty officers may be found in NATOPS Manual, General Flight and Operating Instructions, and the CVA/CVS NATOPS Manual. Ground and flight procedures for individual aircraft are contained in the NATOPS Manual for each specific aircraft.

The ground procedures will in most cases parallel those found in the General Information and Servicing volume of the Maintenance Instructions Manual for the specific aircraft concerned.

Instructions in appropriate safety precautions are required to be given and positive action must be taken in the case of willful violations.

The safety program will generally involve three areas of attention—the posting of the most important safety precautions in appropriate places, the incorporation of safety lessons in the formal training program, and frequent checks for understanding and compliance during the day-to-day supervision of work.

Fixed posters and signs must be placed in locations where personnel are most likely to see them and where they will provide the maximum impact. They should be relevant to activities engaged in by personnel located in the space where they are displayed and removed or rotated to enhance their effectiveness. Visual information should be presented in a positive manner so that it will impart appropriate precautionary measures without instilling fear. Appropriate safety posters may be obtained from the activity safety officer.

Posted safety precautions are more effective if they are easily complied with. For example, a sign on a tool grinder reads "goggles required," so one or more pairs of safety goggles should be hanging within reach at the machine. Similarly, the protective clothing poster in the welding shop should be backed up with readily available aprons, gloves, shields, etc.

The formal safety training sessions should utilize films, books, visual aids, or any other suitable technical material. The men should be told more than just what or what not to do. Each safety subject should be explained in detail. The results of unsafe acts are usually the most dramatic and easiest remembered. Causes of accidents and contributing factors should be reviewed and analyzed. Many good ideas for accident prevention have been developed in training sessions.

An extensive series of lessons may be developed over a period of time as latent hazards are recognized, and this will aid in keeping the sessions interesting while avoiding too frequent repetition.

It may be well to mention the new man in the work center at this point. A separate safety indoctrination lesson which covers all the major hazards of the work center should be given the new man as soon as he reports for work. No supervisor with an effective safety program and an excellent work center safety record wants to take the chance that the new man will be injured before attending the complete series of safety lessons.

In the third area of safety program administration–followup–the supervisor will have one or more key members of the work center who attend the quality assurance safety meetings. These members will provide inputs regarding safety violations and potential hazards that should be advertised and disseminate information discussed during meetings to all personnel in their respective work area. These members as well as supervisors provide a definitive communication link in pointing out peculiar activity hazards and current violations and can take immediate action to remedy such situations. Subordinate petty officers must assist in monitoring the program on a continuous basis. Also included in the followup area is a responsibility of the supervisor to inquire as quickly and thoroughly as possible into circumstances of accidents and reports of unsafe practices and the taking of action and/or making of recommendations.

Interpretation of Safety Directives and Precautions

The safety precautions contained in Safety Precautions for Shore Activities are designed to cover usual conditions ashore. Commanding officers and others in authority are authorized to issue special precautions to their commands to cover local conditions and unusual circumstances. The supervisor will have to apply both sets of rules in the administration of his work center safety program.

Safety directives and precautions should be followed to the letter in their specific application. Should any occasion arise in which any doubt exists as to the application of a particular directive or precaution, the measures to be taken are those which will achieve maximum safety.

When new safety posters or precautions are posted, it is the responsibility of the supervisor to correctly interpret their application to his men. In this way he will be able to achieve a unity of thought and action in the observance of the required safety rule.

The organizations's safety officer is available to assist in interpreting and suggesting ways of implementing various safety directives and precautions. Current directives require that a safety officer or safety engineer be assigned as head of the safety department, division, branch, or section, whichever is applicable, at all shore stations.

In most instances the hazards involved and the applicable precautions for a given type of work are the same whether the work is done afloat or ashore. However, the safety program must account for inherent dangers and provide precautions necessary for afloat operations that are not present ashore. An example of this would be a hazard peculiar to flight deck operations.

TRAINING OF PERSONNEL

The proper training of Aviation Fire Control Technicians is a necessity, and is an important responsibility of the senior AQ. An inspection of a well-run, efficient, shop would undoubtedly reveal a flexible training program, with competent instructors. The competent instructor should utilize each opportunity to instruct less skilled AQ personnel in the varied tasks that may be assigned. This training may be accomplished by many methods such as lectures, movies, training aids, group discussions, on-the-job training, etc. Due to limited facilities, however, most maintenance training at the work center level is either by the lecture method or on-the-job training method.

Navy training schools, factory training, and in-service training are available for the training of maintenance personnel. The class A and B schools provide the necessary prerequisites for the specialized supplementary training provided on specific aircraft, equipment, groups of related equipment, or specialized techniques (maintenance management) by the various NAMTraDet's.

Even if a supervisor is fortunate enough to have a group of men who are highly skilled and well trained, he will find that training is still necessary. For example, the training of strikers and lower rated men for advancement examinations is a continuing, never-ending process. The Navy rotation policy being what it is, the best men will eventually be transferred and replacements will be received aboard. The replacements will, in most instances, require training before they can be relied on to take their places as effective members of the shop organization. These and similar problems require the supervisor to be well versed in the several aspects of training—able to set up as well as conduct an effective inservice training program for assigned personnel.

ORGANIZING THE TRAINING PROGRAM

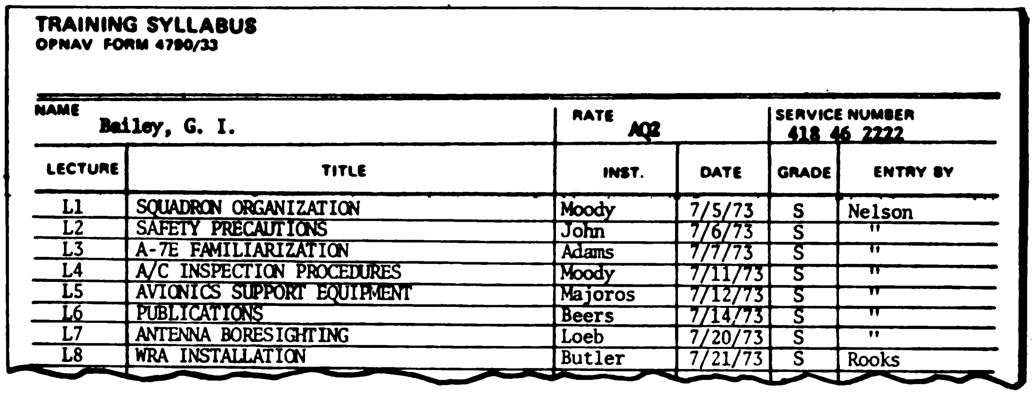
Organizing a training program involves such considerations as planning lessons and job plans, selecting and qualifying instructors, making arrangements for classroom space, phasing the training program with the scheduled workload, procuring visual and other training aids, and determining teaching methods for each lesson or lesson series.

The subject matter areas to be included in the training program are: (1) material relating to maintenance of aircraft supported; (2) general material required by the men for advancement in rating examinations; and (3) material relating to safety. In most cases lessons will fall under more than one of the subject areas.

Once it has been determined what publications will adequately cover the subject areas, the material must be divided into lessons, and lesson guides prepared. The lesson guides for each lecture are prepared in accordance with the standard format provided in OpNav Instruction 4790.2 (Series). The lectures are numbered to provide a means of recording each man's progress within his individual training folder. A training syllabus, similar to the one illustrated in figure 2-1, is prepared for each man in the work center and provides a handy index to the state of training of the work center personnel as a whole.

Whether the supervisor teaches the lessons himself or assigns other petty officers to conduct them depends on the state of training of his first and second class petty officers. A requirement for advancement for third class petty officers and nonrated personnel is satisfactory completion of the correspondence course based on Military Requirements for Petty Officer 3 & 2, NavPers 10056 (Series). This text book sets forth some of the basic principles of training in general and teaching in particular.

An advancement requirement for second and first class petty officers is satisfactory completion of the correspondence course based on Military Requirements for Petty Officer 1 & C, NavPers 10057 (Series). The latter text expands



TRAINING SYLLABUS
OPNAV FORM 4790/33

NAME Bailey, G. I.
RATE AQ2
SERVICE NUMBER 418 46 2222

LECTURE	TITLE	INST.	DATE	GRADE	ENTRY BY
L1	SQUADRON ORGANIZATION	Moody	7/5/73	S	Nelson
L2	SAFETY PRECAUTIONS	John	7/6/73	S	"
L3	A-7E FAMILIARIZATION	Adams	7/7/73	S	"
L4	A/C INSPECTION PROCEDURES	Moody	7/11/73	S	"
L5	AVIONICS SUPPORT EQUIPMENT	Majoros	7/12/73	S	"
L6	PUBLICATIONS	Beers	7/14/73	S	"
L7	ANTENNA BORESIGHTING	Loeb	7/20/73	S	"
L8	WRA INSTALLATION	Butler	7/21/73	S	Rooks

AQ.1
Figure 2-1.—Training syllabus.

and amplifies training theory and introduces job analyses, training aids, and testing. For the first time in his career the prospective First Class Aviation Fire Control Technician is required to demonstrate his ability to formally teach, use various training aids, and prepare and administer written tests. In order to demonstrate correct instructional techniques the supervisor may elect to teach certain lessons himself or assign them to a competent instructor for the same purpose. Later he may assign less proficient petty officers as instructors so that they may acquire the experience necessary for completing their practical factors for advancement.

If at all possible, training sessions should be conducted at the same time of day and on a regular schedule. Training must be scheduled to encompass all working shifts so that all personnel are included in the overall training program. Factors to consider when scheduling lessons are usual flight schedule, meal hours, watches, and availability of classroom.

Some lessons are better suited for one type of instructional technique than others. The type of presentation for each lesson should be planned in advance. This will also facilitate the rotation of the lessons among the petty officers who require experience in teaching.

The effectivity of aviation technical training is greatly enhanced by the use of training aids. The supervisor should always be on the alert for scrap material that can be converted to training aids with minimum expense. He must be aware of the existence of applicable training films and, if they are available, schedule them for showing in conjunction with specific lessons. The squadron or unit safety officer or station safety engineer may usually be depended on to supply training aids in support of shop safety presentations.

When planning a training program, the supervisor should decide where the classroom sessions should be conducted. The space selected should preferably be in a quiet area or at least one with a minimum of noisy distractions. The area should be large enough to accommodate the expected student load and be well lighted. Adequate ventilation will help keep the men awake and interested in the presentation. Convenience is another factor in the selection of classroom space. Some of the desirable space characteristics may, on occasion, have to be sacrificed in order to find a classroom nearer to the working area.

TRAINING PROCEDURES

Inservice training represents a major contribution to the Navy's overall training program. To satisfy the individual activity's particular requirements, the training program must include both lectures and practical training. In this respect, training procedures are of two general types–formal and informal.

Formal Inservice

Formal inservice training is conducted in the classroom through lectures, supplemented by required reading and implemented by the use of all available visual aids. A schedule of training is prepared and published by the maintenance administration officer. This schedule is usually prepared on a monthly basis and lists the subject of the lesson or its identifying syllabus number, the time that the training is to take place, the location of the classroom, the names of the men who are to attend, and the name of the instructor.

Lesson guides are prepared by designated officers, petty officers, and in some instances by Contractor Engineering Technical Services/Navy Engineering Technical Services personnel. The lesson guides should contain the lecture number, title, date prepared and by whom, objectives of the lesson, time normally required in presenting the lesson, list of instructional aids, list of references with which the instructor should become familiar before teaching the lesson, outline for presentation, summary of the lesson, and questions and answers to check for understanding.

When a petty officer has been assigned to instruct a given lesson, it is his responsibility to procure a copy of the lesson guide and from it prepare his personalized lesson plan. Since lesson plans are prepared by the individual instructor, they may differ slightly from instructor to instructor. They must cover the information outlined in the lesson guide. The quality of the lesson given will reflect the amount of preparation given by the instructor plus his experience and ability to instruct.

Informal Inservice

Informal training is the practical instruction of men in the performance of maintenance tasks by means of demonstration and imitation under personal supervision in the shop or on the operating line. Nearly every maintenance task that is undertaken presents an opportunity for on-the-job training. The experienced men of the work center are utilized as fully as possible in demonstrating and imparting their skills to the less experienced.

Under this system, the trainee has the opportunity to actually do the job under the supervision of an experienced petty officer. The only equipment necessary is the job itself. It is necessary, of course, that the instructor have an interest in the job and the skill to do it well. The striker or trainee will learn by seeing the job performed, and he will gain experience by having a chance to participate in the accomplishment of the job.

The nature of informal training makes regular scheduling impracticable. Actually, it is done at every opportunity. A training syllabus is prepared under the guidance of the maintenance officer, with content and scope corresponding with practical factor requirements of the personnel. The degree of success in on-the-job training (OJT) depends on the degree of recognition by each individual of his responsibility to his outfit to impart his skill and knowledge to the man who is trying to learn.

TRAINING DOCUMENTATION AND RECORDKEEPING

Maintenance activities, except those that are specifically excluded, should comply with the manhour accounting procedures outlined in OpNav Instruction 4790.2 by submitting manhour accounting cards to reflect the accomplishment of formal inservice training. Procedures for submitting manhour accounting cards are provided in Military Requirements for Petty Officer 3 & 2, NavPers 10056 (Series) and OpNav Instruction 4790.2.

The individual Training Syllabus Sheet provides a record of formal lectures attended by each man in the work center. A report of practical training (OJT) should be made to the division officer at regular intervals. This will indicate to the division officer that a man has fulfilled a satisfactory level of skill to justify completing of the various items listed on the individual's practical factors for advancement sheet. The formal training syllabus record and the record of practical training will indicate that required training has been completed in all areas or that a need for special training exists and further certifies when the individual may be considered qualified for advancement.

REQUIRED READING AND MAINTENANCE INFORMATION RECORD

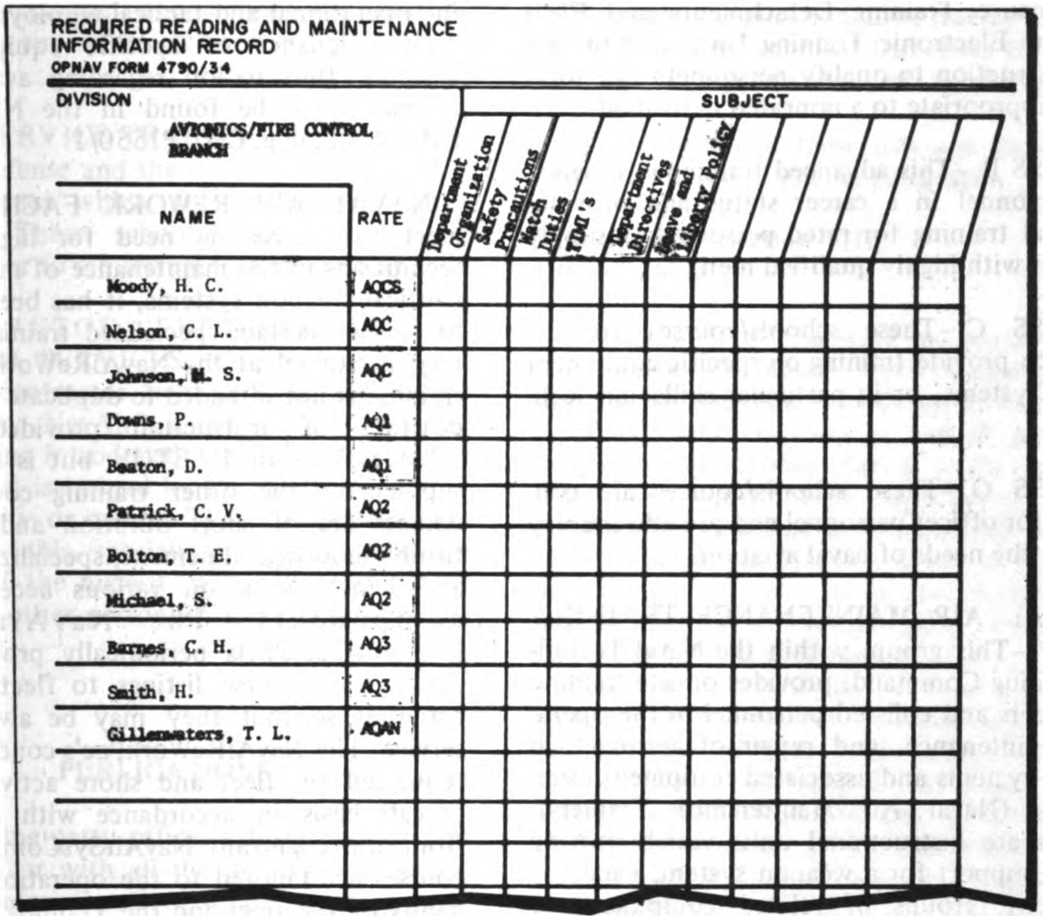
Certain directives and publications are routed to the various work centers as maintenance information, and copies of such maintenance information must be disseminated and retained until it is no longer applicable. Information should be placed in a required reading file that is available to all hands in the work center. When new material is received, it is placed in the "active" required reading file until it is read and initialed by each man in the work center. It may be necessary for the work center supervisor to amplify or clarify some information so that it will be properly understood.

Once all personnel in the work center have read and initialed the material, it is placed in the "standing" required reading file for use in indoctrinating new personnel and for periodic review by those personnel who may require it. Newly assigned personnel should read and initial both the active and standing file. If copies of directives or publications are not available for the required reading file, a cross-reference sheet indicating the general content of the subject matter and its location is utilized to insure that personnel are thoroughly aware of all information that could affect their actions.

OpNav Form 4790/34 (Fig. 2-2) or its equivalent is used to maintain records on required reading.

TRAINING SCHOOLS

Naval schools and courses are maintained to assist forces afloat by providing training that is not available at the local level. New men reporting to a command who are a graduate of a service school or course will not require as much



REQUIRED READING AND MAINTENANCE INFORMATION RECORD
OPNAV FORM 4790/34

DIVISION
AVIONICS/FIRE CONTROL BRANCH

		SUBJECT											
NAME	RATE	Department Organization	Safety Precautions	Watch Duties	TDMI's	Department Directives	Leave and Liberty Policy						
Moody, H. C.	AQCS												
Nelson, C. L.	AQC												
Johnson, M. S.	AQC												
Downs, P.	AQ1												
Beaton, D.	AQ1												
Patrick, C. V.	AQ2												
Bolton, T. E.	AQ2												
Michael, S.	AQ2												
Barnes, C. H.	AQ3												
Smith, H.	AQ3												
Gillenwaters, T. L.	AOAN												

AQ.2

Figure 2-2.—Required reading and maintenance information.

training as a nonschool graduate to become a useful member of a fighting team. Senior AQ's are responsible for insuring that each man is adequately trained to perform assigned tasks/jobs. With planning, a supervisor can schedule his personnel to the various schools and courses available to aid him in complying with mandatory requirements for having school graduates perform certain jobs.

Classes of Schools

The Naval Technical Training Command, with headquarters at Naval Air Station Memphis, Millington, Tennessee, has numerous activities where intensive training is conducted in several categories. Detailed information for obtaining school quotas is contained in the Navy Formal Schools Catalog, CNT P1550/1.

CLASS P.—Class P schools/courses are designed to provide training at a preparatory level for group IX (aviation) ratings, and to provide nonrated aviation personnel with the information and practical training necessary to complete the qualifications for advancement to airman.

CLASS A.—Class A schools/courses are generally limited to providing those prerequisites necessary to prepare trainees for specialized training which is offered by Naval Aviation

Maintenance Training Detachments and Fleet Airborne Electronic Training Units and to provide instruction to qualify personnel to perform duties appropriate to a nonrated individual.

CLASS B.—This advanced training is designed for personnel in a career status and provides technical training for rated personnel to supply the fleet with highly qualified men.

CLASS C.—These schools/courses are designed to provide training on specific equipment and/or systems, or in particular skills and techniques.

CLASS O.—These schools/courses are conducted for officer personnel and provide training to meet the needs of naval aviation.

NAVAL AIR MAINTENANCE TRAINING GROUP.—This group, within the Naval Technical Training Command, provides on-site training for officers and enlisted personnel in the operation, maintenance, and repair of aeronautical weapon systems and associated equipment using NAMT's (Naval Air Maintenance Trainers). NAMT's are instructional units which provide training support for a weapon system, a specific equipment, groups of related equipment, or specialized techniques. Further information is contained in the Navy Formal Schools Catalog, CNT P1550/1.

Other Technical Training

Other courses available to personnel on specific types of equipment or systems are discussed in the following sections.

FAETU (FLEET AIRBORNE ELECTRONIC TRAINING UNIT).—The FAETU's are charged with the instruction of Fleet personnel in courses covering operational and tactical employment of specific equipment and systems. Information regarding availability of courses is contained in the ComNavAirLant/ComNavAirPac 1500 Series Instructions.

AIR RESERVE TRAINING COMMAND ASW TACTICAL SCHOOL EAST/WEST.—These schools are primarily charged with the instruction of reserve personnel in courses covering operational and tactical employment as well as maintenance of specific equipments and systems. Information regarding availability of courses is to be found in the Navy Formal Schools Catalog, CNT P1550/1.

NAVAL AIR REWORK FACILITIES.—To meet the increasing need for highly trained technicians in the maintenance of modern aeronautical weapon systems, it has been necessary to provide certain specialized training for military personnel at the NavAiReWorkPac's. This training is not intended to duplicate any present courses of instruction provided by the NAMTraDet's or FAETU's, but is intended to supplement the other training courses. Most courses are of short duration and emphasize troubleshooting, alinement, specialized training, and bench work on various accessories and components. The NavAirSysComRepLant/Pac/Pncla periodically provide course catalogs or course listings to fleet and shore activities so that they may be aware of this service. The NavAiReWorkPac's conduct courses requested by fleet and shore activities on an on-call basis in accordance with instructions from the cognizant NavAirSysComRep. These courses are tailored to the operational requirements of the fleet and the Training Commands and are listed in NavAirRepLant/Pac/Pncla Instruction 1500.2 (Series).

AVIATION READINESS TRAINING.—The type commanders have implemented aviation readiness training procedures on specific aeronautical weapon systems for aviation ground officers and key enlisted maintenance personnel. Training is conducted by the Naval Air Maintenance Training Group and their various detachments, Fleet Air Electronics Training Units, and Readiness Training Squadrons in accordance with syllabuses approved by the type commanders. Detailed procedures for the various types of weapon systems, equipments, and missions may be found in instructions promulgated by the type commanders. Enlisted maintenance personnel receive NAMTraDet/FAETU training courses in familiarization, operation, and/or maintenance of the specific weapon system or equipment which they will be required to maintain. In addition, the Readiness Training Squadrons provide inservice training, and those personnel who successfully complete the training course are awarded the appropriate NEC.

INTERSERVICE TRAINING. – The Department of Defense and the other services conduct schools/courses which are available to Navy personnel. These schools/courses should be checked prior to requesting factory training.

CONTRACTOR ENGINEERING AND TECHNICAL SERVICES.–Contractor plant services and contractor field services training are provided by NavAirSysCom on new weapon systems being introduced to the fleet. A nucleus of personnel is trained by the contractor either at his facility or on-site. The type of personnel ordered to this specialized training program must be of the highest caliber and capable of instructing other personnel upon completion of the training.

PUBLICATIONS

The leading petty officer's duties require him to be familiar with all the publications associated with administration, supply, ordering, and maintenance of aviation electronic equipment pertaining to his assigned unit. He may be called on to complete forms, originate reports, originate requisitions, and perform many other duties consistent with the administration of an avionics division. Unless he has mastered the details of securing and maintaining publications, his value to his superiors and his ability to instruct the men under him are limited.

PUBLICATIONS INDEX

The Publications Index is made up of five parts, each of which serves a specific purpose. They are identified as follows:

Navy Stock List of Forms and Publications, NavSup Publication 2002, Section VIII, Parts C and D, Numerical Sequence List (also referred to as Numerical Index).

Equipment Applicability List (Volumes 1 through 7), NavAir 00-500A.

Aircraft Application List, NavAir 00-500B.

Directives Application List, NavAir 00-500C.

Letter Type Technical Directives Equipment and Subject Application List, NavAir 00-500D.

A description of these lists and their uses is presented in the following paragraphs.

NavSup 2002, Section VIII, Parts C and D

Section VIII of this stock list contains Naval Air Systems Command (NavAirSysCom) publications. This section is made up of four parts–A, B, C, and D. Parts A and B pertain to ordnance publications. Part C is the numerical listing of manual type aeronautic technical publications, and Part D is the numerical listing of letter type publications. These two, Parts C and D, are referred to as the Numerical Sequence List of Numerical Index of the Naval Aeronautic Publications Index.

Part C of this stock list contains a numerical listing, by code number, of available aeronautic technical manual type publications. In addition to the code number, the publication title, security classification, and date of issue or date of latest revision are given. The instructions for using the stock list include an explanation of the code number system used to identify the manuals by subject group. Also included in this section is information on ordering and methods of procurement of publications. Another section of the stock list is devoted to a cross-reference index of Air Force, NavShips, and NavOrd publication numbers to the NavWeps publication numbers.

Part D of the stock list contains a listing of the letter type technical directives. These are grouped by subject matter and, in addition to the same information that is listed for manuals in Part C, an effective date is included if applicable.

All titles of publications listed in these stock lists are unclassified unless marked "1" (Confidential) in the column headed SC (security classification). However, this marking is not classification authority. The bimonthly supplement contains information pertaining to changes in classification action on a when occurring basis. This supplement, in itself, is authority for making classification changes on NavAir publications.

NavAir 00-500A

Naval Aeronautic Publications Index, NavAir 00-500A, Equipment Applicability List, is a cross-reference index listing of Naval Air Systems Command (NavAirSysCom) publications of aircraft components and related equipment according to model, type, or part number.

Since this index contains several thousand entries, one volume would be very cumbersome to use. For this reason, this index is divided into several volumes. At the time of this writing, there are seven volumes. Each of the first six volumes contains 400 pages, and volume 7 contains the remaining entries.

With the exception of several small sections in the first part of volume 1, the Equipment Applicability List is one continuous index of model, type, or part numbers in alphanumeric sequence.

In addition to an introduction, which explains the heading at the top of each page, the other sections in the first part of volume 1 pertain primarily to manuals for aircraft, weapons systems, and aircraft engines. Therefore, the publication numbers are listed according to aircraft, aircraft engine, and weapons system designation.

The Equipment Applicability List should be used when attempting to determine what publications are available on a particular item of equipment when the manufacturer and part number of the item are known.

NavAir 00-500B

The Aircraft Application List, NavAir 00-500B, contains a listing of all manuals grouped according to their application to an aircraft. This part of the index does not contain listings of any letter type publications, and all manuals are listed by publication code number only.

A list of basic numbering categories is provided in the front of the book. This list may be used in determining the general type of equipment covered in a publication. For determining the specific item of equipment covered by a publication and the title of the publication, reference should be made to Part C of Section VIII in NavSup Publication 2002.

The Aircraft Application List is especially handy for determining what manuals are available for a particular model of aircraft. Included under each model is a complete listing of applicable manuals. This listing includes all allowance lists, aircraft manuals, engine manuals, accessories manuals, etc., pertaining to that particular model of aircraft.

NavAir 00-500C

The Directives Application List by Aircraft Configuration, NavAir 00-500C, contains a listing of the active Naval Air Systems Command letter type technical directives with respect to their applicability to aircraft. The lists in this volume are arranged first by aircraft series, second by aircraft configuration, and third by Airframe/Aircraft Bulletin and/or Change numbers. (NOTE: Configuration refers to modifications made to a basic aircraft model. For instance, A-4A, A-4B, TA-4F, etc., are all different configurations of the A-4 aircraft model.)

NavAir 00-500D

The Equipment and Subject Applicability List, NavAir 00-500D, is a relatively new addition to the Naval Aeronautic Publications Index. It contains a cross-reference index listing of Naval Air Systems Command letter type technical directives. It serves the same purpose for letter technical directives as the Equipment Applicability List, NavAir 00-500A, does for technical manuals. However, since NavAir 00-500D lists only those model/type part numbers for which technical directives have been issued, it is much smaller than NavAir 00-500A. The complete list is contained in one volume but is divided into two parts. Part A is the Equipment Index and Part B is the Subject Index.

Part A contains a listing of all Naval Air Systems Command letter type technical directives on aircraft components and related equipment by model/type part number. Each number is listed in alphanumeric sequence within its cognizant equipment series. At the present time, Part A is divided into nine series. The Avionics Series is of most interest to the AQ.

Part B of NavAir 00-500D contains a listing of active Naval Air Systems Command letter type directives by subject. This part of the list pertains primarily to Airframe Bulletins and Changes.

Each List in the Naval Aeronautic Publications Index is updated at regular intervals by the issuance of a new list. In addition, some of these lists are kept current by the periodic issuance of supplements between issues of the basic list. The dates and intervals of the issuance of new lists and supplements have changed from time to time in the past.

At the time of this writing, the Numerical Index (Parts C and D of NavSup Publications 2002) is issued annually in September. Supplements are issued bimonthly between each basic issue. The Equipment Applicability List, NavAir 00-500A, is issued annually in November. This list is kept current by the issuance of quarterly supplements between each basic issue. The Aircraft Application List, NavAir 00-500B, is issued in March and September, and the Directives Application List by Aircraft Configuration, NavAir 00-500C, is issued in January and July of each year. Supplements are not issued for these lists.

The Equipment and Subject Application List, NavAir 00-500D, is issued in May and November of each year, and supplements are issued as the information is developed.

Supplements list all aeronautic publications distributed during the previous period, and those publications that have been superseded, canceled, or revised. Supplements are cumulative; that is, all material from the preceding supplement is incorporated in the lastest supplement. Therefore, at any given time, not more than one supplement is in effect for any list. Naturally, the reissue of a basic list cancels the outstanding supplement.

Supplements for the Numerical Index (Parts C and D of Section VIII of NavSup Publication 2002) are identified by the word "supplement" printed near the upper right-hand corner of the cover. Supplements to the NavAir 00-500A Series publications are identified by the word "supplement" printed in the middle of the cover page.

TECHNICAL DATA

Technical data are provided in numerous forms for training, operations, maintenance, calibration, repair, storage, and shipment of weapons systems and equipment. These data are important elements of the logistics support necessary for the insurance of fleet readiness and equipment availability. Personnel training, operation, and maintenance of today's sophisticated, high-performance weapons systems demand the development and dissemination of accurate, clear, and concise technical information. Investigation proves that a worker's ability to support and maintain modern equipment is directly related to the quality of the documentation and the training program established therefor.

Technical data are recorded information used to define a design and to produce, support, maintain, or operate items of defense material. These data may be recorded graphic or pictorial delineations in media such as technical manuals, drawings, or photographs; text in specifications, related performance, or design type documents; and machine forms such as punched cards, magnetic tape, or computer memory printouts that may be retained in computer memory.

Technical documentation is recorded technical data. The methods used to record data for technical documentation are microfilm, technical directives, tapes, manuals, etc.

TYPES OF TECHNICAL DATA

Technical data are presented in varied forms; however, data available to fleet and repair activities fall into three major categories: technical manuals, technical directives, and engineering drawings and associated data.

Technical Manuals

To attain a satisfactory state of readiness, technical manuals are developed, published, and distributed concurrently with hardware. Periodic changes and revisions are issued as necessary to insure that manuals continually reflect equipment configuration and current operational and support concepts and procedures. Technical manuals released under the authority of ComNavAirSysCom are considered the only authorized source of the information provided and the instructions contained therein are mandatory.

Technical Directives

For rapid documentation of weapons systems or equipment change information, for citing of special inspection requirements, or for clarifying or emphasizing operational or maintenance parameters, NavAirSysCom issues information through the technical directive system.

Engineering Drawings and Associated Data

This category of data is procured and issued in support of detailed maintenance and repair of weapons systems and equipment.

NAVAL AIR SYSTEMS COMMAND TECHNICAL MANUAL POLICY

Command policy objectives are directed toward providing the most adequate and accurate technical manuals to support training, operations, and maintenance. A constant surveillance is maintained to permit improvement in the manual system. This is to provide feedback quickly for corrective changes, and revisions to using activities.

A complete technical data package is not required by each operating or support activity for effective logistic performance. Aviation activities, station maintenance divisions, and other nonindustrial units are normally provided all required technical data in the form of technical manuals and technical directives. Only industrial activities are normally provided engineering data in addition to manuals and directives.

Data are prepared for support of the five major areas of coverage defined as follows:

1. Operations. Technical manual data describing the operation of major weapons systems or equipment; i.e., in the case of aircraft, it describes the aircraft, its installed systems, handling and servicing requirements, operational limitations, etc.
2. Maintenance. Technical manual data, specialized test tapes, diagnostic information, and engineering data are designed to provide general and specific instructions required for performance of organizational, intermediate, and depot levels of maintenance and repair.
3. Training. Technical manuals provide for support of operational and maintenance training.
4. Configuration Modification. Data necessary for alteration or modification of systems or equipment are disseminated to using activities through the technical directives system. Concurrent changes to affected manuals are prepared and released through the manual distribution system to reflect the maintenance requirement for all system configurations.
5. Supply Support. Coordinated action between the NavAirSysCom, ASO, and SPCC provides supply documents, such as allowance lists and initial outfitting lists. Illustrated parts breakdown manuals are prepared and distributed for specific systems and equipment for identification and supply support of spare component and spare parts. PPB's (Provisioning Parts Breakdowns) and MEAR's (Maintenance Engineering Analysis Records) are also provided when required to support maintenance and/or technical logistics operations.

Types of Technical Manuals

Technical manuals are selected and prepared to cover general information as well as specific areas of equipment coverage. Every effort is made to insure that content of individual manuals (or sections thereof) are directed to specific work areas as well as maintenance levels. This eliminates unnecessary duplication and clearly presents the required information to the user. Some of the major types of manuals and typical examples are listed in the following paragraphs.

1. Operational Manuals are specifically prepared to define methods and procedures for conducting operational tasks or exercises. The following are examples of Operational Manuals:

NATOPS (Naval Air Training and Operating Procedures) Series are specifically prepared in support of aircrew personnel. The NATOPS provides standardized ground and flight operational procedures, training requirements, and other operational information of a technical nature. The data are tailored to ships and particular models of aircraft in accordance with CNO directives.

Tactical Manuals define aircraft operational parameters, weapons/stores clearances, and combat capabilities and limitations as authorized by CNO. The manuals are prepared under the technical cognizance of the Commander, Operational Test and Evaluation Force, and the information presented therein is mandatory.

2. Maintenance Instructions Manuals provide general and specific instructions concerning material description, principles of operation, and maintenance and repair data for the levels of maintenance authorized by the maintenance support plan. The manuals usually consist of a series of volumes numbered in the airframe series and are normally broken down by the assigned organizational and intermediate levels of maintenance.

3. Component and Equipment Manuals are separately selected manuals that normally provide component and equipment coverage through the intermediate and depot levels of maintenance. These manuals usually support material installed in multiple equipment applications, and are identified by specially assigned category manual numbers; i.e., engines, avionics, armament, etc.

4. Work Unit Code Manuals provide a listing of assigned numeric codes for identification of installed systems or equipment. Discrepancies and maintenance actions are reported by code into the 3-M system. Reported information is entered on electronic data processing cards for processing statistical failure and usage reports. These reports are used as a management tool for the development and implementation of equipment design, maintenance, material, and supply improvements.

5. Periodic Maintenance Requirements Data are specifically designed to sequentially define periodic scheduled maintenance and inspection requirements. Examples of each are as follows:

The PMRM (Periodic Maintenance Requirements Manual) is designed for use as an air weapons system scheduled maintenance coordinating and planning document for all levels of maintenance. This series prescribes all scheduled and periodic maintenance for a given weapon system, including its subsystems, components, and ground support equipment.

Maintenance Requirements Cards define the minimum periodic maintenance requirements necessary for efficient and effective operation of a specific air weapon system, its installed equipment, and its ground support equipment. Information includes inspection tasks which verify the existence of correct conditions or isolate equipment discrepancies. Data related to proper clearances, tolerances, pressures, operating limits, parts replacement, and special tool requirements are also included.

6. GSE (Ground Support Equipment) Manuals define the correct procedures for the functional operation, maintenance, and servicing of GSE. When required, these manuals also include calibration of GSE.

7. IPB's (Illustrated Parts Breakdowns) provide system, subsystem, and individual parts identification and replacement source data. Coverage is normally contained in separate manuals or in a special section of the maintenance manual. Identification is enhanced by graphic display of exploded views and assembly breakdown of systems and equipment designated as replaceable or repairable.

IPB's are issued for all aircraft, contractor/government furnished equipment components and equipment, related hardware, and GSE, for which bit and piece support is to be provided. Separate IPB's are not provided for those items of CFE (Contractor Furnished Equipment) for which complete breakdown is contained in the airframe IPB. IPB's do not identify supply data such as FSN's. Part number data must be cross-referenced to NavSup cross-reference catalogs to identify FNS's.

Technical Data Not Under NavAirSysCom Cognizance

Many other Navy publications not under the cognizance of NavAirSysCom are of interest and importance to the AQ; for example, training manuals, correspondence courses, Safety Precautions, the Landing Party Manual, etc.

ARMY AND AIR FORCE PUBLICATIONS.–Other publications from which valuable information and instructions may be gained are Department of the Army publications and Air Force publications. Examples of these are such publications as Technical Manuals, Technical Bulletins, Field Manuals, Standard Nomenclature Lists, etc.

ORDNANCE PUBLICATIONS.–These were formerly prepared by the Bureau of Naval

Weapons; and if printed prior to May 1966, they carry the NavWeps identification. They are now prepared by the Naval Ordnance Systems Command; or in some cases concerning airborne ordnance, they are prepared by the Naval Air Systems Command and are designated NavAir OP's.

TECHNICAL DIRECTIVES

The TD (Technical Directives) system is the authorized medium for directing the accomplishment and recording of modifications and one-time inspections of NavAirSysCom accepted equipment in either the contractor's or Navy's possession.

Types of Technical Directives

Technical directives are issued as formal (letter type) and interim (message type) directives. A formal TD is a document issued as a change, or as an amendment or revision thereto, and promulgated by letter. An interim TD is a document issued as a bulletin or change, or as an amendment or revision thereto, and promulgated by message to insure expeditious dissemination.

CHANGES.—A change is a document comprised of instructions and information which directs the accomplishment and recording of a material change, a repositioning, a modification, or an alteration in the characteristics of the equipment to which it applies.

BULLETINS.—A bulletin is an interim document, comprised of instructions and information, which direct an initial inspection to determine whether a given condition exists, and directs an interim revision to the TM series, if applicable, for continuing inspections. It specifies what action is to be taken if the condition is found or not found. Inspections may result in a need for corrective action requiring the use of approved repair procedures involving material in order to restore design integrity, as long as configuration control is not jeopardized.

AMENDMENTS.—An amendment is a document comprised of information which clarifies, corrects, adds to, deletes from, makes minor changes in requirements to, or cancels an existing TD. A maximum of three amendments may be applied to any TD, each remaining in effect until rescinded or superseded by a revision. Amendments may not be used to cancel an amendment.

REVISIONS.—A revision is a completely new edition of an existing change or bulletin. It supersedes the original directive or revision and all existing amendments.

INTERIM TECHNICAL DIRECTIVES.—ITD's (Interim Technical Directives) are technical documents used to direct the accomplishment and recording of modifications and one-time inspections of NavAirSysCom accepted equipment. They are promulgated by message.

TECHNICAL LIBRARY

The aeronautical technical library serves two important functions: First, it provides a central source of up-to-date information for the use of all technical personnel in the current performance of their work; and second, it is an excellent source of reference information to facilitate personnel training and individual improvement. To perform these functions properly, the technical library must contain at least one copy of all publications affecting assigned aircraft, ordnance, and related equipment, in accordance with the maintenance level responsibility involved. Initial outfitting allowances are sufficient to establish the technical library. However, additional copies of selected publications must be ordered for ready availability and use at the working levels.

Management of the technical library is a function of the QA Division. This function includes the determination of technical manuals required to support the maintenance organization, receipt, and distribution control of these manuals, as well as the responsibility for insuring manual updating throughout the maintenance organization. These responsibilities also apply throughout the entire activity when the Maintenance Department has cognizance of all aeronautical technical manuals for the activity.

Modern technology is constantly changing. Today's best practices may be modified, totally revised, or made obsolete tomorrow. This is not always a planned or intended condition, but it must be accepted and dealt with. Such a condition requires that prompt action be taken to change and revise material related to the technical information and data used by maintenance and operations personnel. The urgency of this action depends upon the type of information involved and the frequency of reference to the affected directives or manuals. However, technical data change and revision material, once it has been screened and routed, should not be allowed to accumulate at any point. Procedures must be established throughout the organization to insure prompt action in revising and updating all technical information and data. It is mandatory that those responsible for the management of the technical library also be responsible for insuring that technical change and revision material reaches all department levels having copies of the affected directives or publications.

TPL (Technical Publication Location Cards) should be maintained in the QA Division to indicate the location of all publications within the department. Proper use of this card will provide effective technical manual management within the central and dispersed libraries. Change Entry Certification form (OpNav Form 5070-12) should be used to insure that all change and revision material is entered in the directives and manuals that are not physically maintained in the technical library.

PROCUREMENT OF DATA

The AQ supervisor must continue an effective program of review of the publications and other technical data required by his department, division, branch, or crew. Publications and directives are provided to aid the supervisor and worker in meeting the commands commitments. As new data are published, it must be made available to the worker. This is a responsibility of the supervisor, who must know the procedures for requisitioning and how to be placed on the automatic distribution list.

MAILING LIST REQUEST FOR AERONAUTICAL TECHNICAL PUBLICATIONS (NAVAIR FORM 5605/3)

Future issues of aeronautical publications and technical directives that are needed on a continuing basis can be received automatically by submitting two copies of NavAir Form 5605/3 to Naval Air Technical Services Facility (NATSF) in Philadelphia, Pa. When new publications or directives are published, NATSF automatically makes distribution to activities on the Standard Navy Distribution List. (This list is prepared from the NavAir Forms 5605/3 received.) NavAir Form 5605/3 is a four-part form. Each part is used to request addition to the mailing list for the types of publications listed on each part. Submission of this form is normally accomplished by the Quality Assurance Division for all divisions of a maintenance department in a squadron.

Part 1.–Part 1 of NavAir Form 5605/3 is used when an activity has a continuing requirement for Allowance Lists, Indexes, and General Series Technical Manuals/Directives.

Part 2.–Part 2 of NavAir Form 5605/3 is used when an activity has a continuing requirement for Allowance Lists, Airframe Manuals/ Technical Directives, and Powerplant Manuals/ Technical Directives.

Part 3.–Part 3 of NavAir Form 5605/3 is used when an activity has a continuing requirement for Component Manuals.

Part 4.–Part 4 of NavAir Form 5605/3 is used when an activity has a continuing requirement for Ship Installation Manuals/Technical Directives.

PROCUREMENT OF EXISTING DATA

Manuals that are current cannot be requested on NavAir Form 5605/3. Data that is already distributed is requested in different ways, depending on the type of data and the originator.

NavAirSysCom Manuals

NavAirSysCom manual type publications are ordered by preparing and submitting the Single Line Item Requisitioning System Document (DD Form 1348 or DD Form 1348M) in accordance with the Military Standard Requisitioning and Issue Procedure (MILSTRIP) as outlined in NavSup Pub 437. These manuals can be received by submitting a DD 1348 to the supply point listed on the inside cover of NavSup Manual 2002. NavSup Publication 2002, Section VIII, Part C, contains a listing of all NavAirSysCom Manual publications and their stock numbers.

NavAirSysCom Letter Type Technical Directives

NavAirSysCom letter type technical directives listed in NavSup Pub 2002, Section VIII, Part D, may be requested on DD Form 1149. The request form should be forwarded to Naval Publications Form Center (NPFC) for all technical directives listed except for those denoted with an asterisk. Those identified by an asterisk may be procured by submitting a letter of justification to Naval Air Technical Service Facility (NATSF) in Philadelphia, Pa.

Instructions and Notices

Navy directives of the instruction and notice type are requisitioned on NavSup Form 1205. Activities desiring additional copies of an instruction or notice should submit the request to the originator of the directive.

FILING CORRESPONDENCE

The Department of the Navy Standard Subject Identification Code, SecNav Instruction 5210.11 (Series) provides a single, standard subject scheme. This classification system is used for classifying Navy and Marine Corps documents by subject throughout the Department of the Navy. SecNav Instruction 5210.11 contains a list of standard subject classification numbers and a list of name-title subject classification codes. Except at activities with an exceptionally large volume of correspondence, files normally are established by subject classification numbers. However, files may be established by name-title codes or a combination of both. These classification numbers/codes and their use are discussed in the following paragraphs.

Directives Issuance System

The directives issuance system provides a uniform plan for issuing and maintaining directives. Directives consist of written matter which prescribes or establishes policy, organization methods, or procedure; require action; or contain information essential to the effective administration or operation of activities concerned.

Instructions are directives of a continuing nature and remain in effect until subsequently canceled. Notices are directives of a one-time nature or directives which are applicable for a brief period of time (usually 6 months or less). Each notice contains a provision for cancellation, on which a specific date is stated for record purposes.

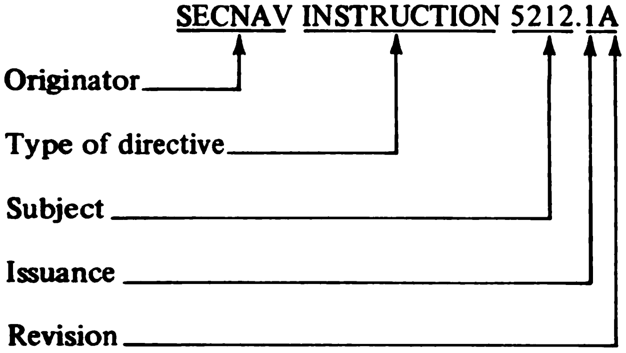
For the purpose of identification and filing, standard subject classification numbers classify Navy correspondence and directives under 13 major series groups. These major series groups are further subdivided by use of the last 3 digits in the major series. The 13 major series groups consist of the following:

1000 Series–Military Personnel.
2000 Series–Communications.
3000 Series–Operations and Readiness.
4000 Series–Logistics.
5000 Series–General Administration and Management.
6000 Series–Medicine and Dentistry.
7000 Series–Financial Management.
8000 Series–Ordnance Material.
9000 Series–Ships Design and Ships Material.
10000 Series–General Material.
11000 Series–Facilities and Activities Ashore.
12000 Series–Civilian Personnel.
13000 Series–Aeronautical Material.

Each office identifies the directives which it originates by the following:

1. The originator's abbreviation.
2. The type of directive.
3. The subject classification number.
4. A consecutive number, preceded by a decimal point (applies to instructions only).
5. A consecutive letter, indicating the revision.

The following example is an identifying symbol assigned to an instruction issued by the Office of the Secretary of the Navy:



Consecutive numbers are assigned to instructions having the same subject classification number to show the order of issuance. For example, the subject number of General Ammunition and Explosives is 8010. An originating office would assign numbers to the first, second, and third instructions which it issues on the same subject as follows: 8010.1, 8010.2, and 8010.3, respectively. The number 8010.1A indicates the first revision of the instruction 8010.1.

Notices are not assigned consecutive numbers because of their onetime nature or brief duration. The subject classification number assigned as the file number of a letter is not assigned a consecutive number.

Name-Title Subject Classification Codes

Name-title codes (alphabetic or alphabetic-numeric codes) are provided for names and titles frequently used by the Department of the Navy. These codes may be used for classifying and filing documents by name or organizational designation except that they are not to be used in assigning subject numbers to directives. Included are symbols for fleet organizations, the United States Government, foreign governments, commercial enterprises and firms; classes of personnel; types of naval activities; and official symbols for classes and types of aircraft, vessels, and guided missiles.

The first letter of the name or title code designates the larger organizational group, and the second or third letters designates a further breakdown of the larger group. For example, "NA" designates naval air stations. The "N" is for the Naval Shore Establishment and the "A" for air stations.

An Arabic numeral added to the letter symbol further subdivides the code. For example:

FF Fleets, Forces, Types, Areas and Sea Frontiers
FF1 U.S. Fleet
FF2 U.S. Task Fleets

Files

File arrangement within any office depends upon the mission of the office and on the volume of its official correspondence. Normally, general correspondence is stored in metal file cabinets. This includes letters, speedletters, and memorandums received or originated by the office.

Folders are used to keep correspondence orderly in the files. Standard file folders are available in two sizes—letter size (9 x 11¾ inches) and legal size (9 x 14¾ inches). The total number of folders and the appropriate primary, secondary, or tertiary subject classification numbers, or the name-title symbols, to be used are determined by the volume of written matter in each category to be filed. There may be no need to establish any folders on some major series groups, while others may require several folders broken down to primary, secondary or tertiary numbers. The subject classification numbers or name-title symbols should be printed on each folder.

The subject classification number placed on the correspondence by the originator assists in determining the correct folder in which to file the correspondence. This number, however, may not be appropriate for the particular office concerned, thereby requiring reclassifying. The proper method of classifying a document for the purpose of selecting the appropriate file is to read it carefully and analyze it, considering the following factors:

1. The most important, definite, or concrete subject mentioned.
2. The purpose or general significance of the document.
3. The manner in which similar documents are requested by users of the files.
4. The subject classification code under which previous documents of a similar nature are filed.

Directives are not placed in the general correspondence files except when copies of instructions and notices are attached to or interfiled in such files when needed to complete a record or document. Instructions are filed in standard three-ring binders and are arranged as follows:

1. In numerical order of subject classification number.
2. By the originating office within each subject classification number.
3. By consecutive number (suffix number) for each originating office.

Notices ordinarily need not be filed because of their brief duration. In cases in which the recipient believes it necessary to file some notices temporarily, they may be interfiled with instructions.

Messages are filed by the date time group number. Normally, two files are maintained—one containing incoming messages and the other containing outgoing messages.

DISPOSITION OF CORRESPONDENCE AND RECORDS

Retention of obsolete and inactive correspondence and records is costly. Such correspondence and records should be destroyed or transferred in accordance with approved records disposal instructions. If this is not performed periodically, the volume of file space required becomes excessive and the files become unwieldy, thus inefficient. The destruction of records is governed by law which requires authorization by proper authority. The authority for destruction of Navy records is contained in SecNav Instruction 5212.5 (Series), Disposal of Navy and Marine Corps Records.

The provisions of SecNav Instruction 5212.5 (Series) are normally amplified by the issuance of local instructions outlining the procedures as they apply locally.

LOCAL DISPOSITION

Not all materials in the files have a record characteristic. In fact, most printed matter found in the maintenance department general files fall in the category of nonrecord material. This includes documents that are copies of those filed in the ship's office or station administrative department, or material accumulated in the process of producing records, but which never acquire a record characteristic themselves.

SecNav Instruction 5212.5 (Series) (part II for shore stations and part III for ships) contains the retention standard for naval records. Record materials are listed by broad subject and the retention period is furnished. Nonrecord material may be destroyed locally as soon as it has served its purpose. Records material may be destroyed upon completion of the retention period.

Unclassified records or nonrecord materials authorized for destruction may be placed in wastebaskets and disposed of in the normal manner for trash. Classified matter authorized for destruction should be destroyed by burning in the presence of two designated witnesses. All persons witnessing the destruction of classified material must have security clearances at least as high as the category of material being destroyed. Classified matter may also be destroyed by pulping, provided destruction of the classified material is complete and reconstruction impossible.

SECURITY

Commanding officers are responsible for establishing security orientation, education, and training programs for all personnel assigned. OpNav Instruction 5510.1 (Series), chapter 3, provides the necessary minimum requirements for implementing these programs.

The central aim of the security education program is to make all personnel "security-minded." To achieve this, a continuing training program must be in use at all levels of the command, with emphasis by the senior petty officers to their subordinates.

Effective security also requires that the handling of classified materials be managed in an efficient manner. Good management practices are important in obtaining effective security control. If security needs are to be met, constant attention must be given to the way in which classified material is handled. The guide for handling and control of classified material is OpNav Instruction 5510.49 (Series).

SECURITY ORIENTATION, EDUCATION, AND TRAINING PROGRAM

The security orientation, education, and training program of each command must include all personnel entrusted with classified information regardless of their position, rank, or grade. The program must be designed to include the following:

1. Familiarize all personnel with the security requirements with which they have to comply for proper performance of their duties and assignments.
2. Remind all echelons of command of their responsibility for assuring that classified defense information is effectively and economically safeguarded.
3. Insure willing, conscientious compliance with security regulations, procedures and practices.
4. Remind all echelons of command of their responsibilities in the classification management program to include classification, upgrading, downgrading and declassification processes as set forth in OpNav Instruction 5510.1 (Series).
5. Advise all personnel who have access to classified information of the hazards of its disclosure to any person not authorized to receive it and of their responsibility for exercising personal vigilance for its protection.
6. Inform all personnel of the techniques and devices employed by foreign intelligence activities in attempting to obtain U.S. classified defense information and of their responsibility for reporting such attempts.
7. The attention of all personnel must be directed to the disciplinary action (Article 0815 of OpNav Instruction 5510.1 (Series)) that may result from violation of security regulations.

Personnel Indoctrination

Persons being assigned to duties requiring access to classified information, prior to being granted access, must be indoctrinated on the security aspects and responsibilities of their assignment. The indoctrination must include the strict prohibition against discussing classified information over the telephone. This is especially important because of the fact that many calls are transmitted through microwave transmitters and can be easily recorded and analyzed. The types of situations to be avoided when talking on the telephone are:

1. Allowing classified information to slip into conversations through carelessness.
2. Disclosure of classified information in order to expedite the completion of a "rush project."
3. Use of codes, "double talk" or attempt to talk around classified information. It should be noted that private codes and "talking around" classified matters presents no real protection against the abilities of a trained analyst.

As part of the indoctrination program, personnel must be instructed to report promptly any of the following types of information:

1. Attempts by representatives or citizens of communist controlled countries to cultivate friendships or to place personnel under obligation.
2. Attempts by representatives or citizens of foreign governments to:

   a. Cultivate a friendship to the extent of placing them under obligation, which they would not normally be able to reciprocate, or by money payments or bribery to obtain information of intelligence value.
   b. Obtain information of intelligence value through observation, collection of documents, or by personal contact.
   c. Coerce personnel by blackmail; by threats against or promises of assistance to relatives living under their control, especially those in a communist country.
   d. Appeal to personnel on a racial, nationalistic, or ideological basis.
   e. Exploit personnel who may be disaffected or in personal difficulties.
   f. Intimidate, harass, entrap, discredit, search, spy on, or recruit for intelligence purposes personnel traveling in communist countries.
   g. Induce personnel to defect or to induce those who have fled from communist countries to redefect.

3. Attempts by Department of the Navy personnel to provide unauthorized services, information, or documents to anyone believed to be in contact with a foreign intelligence service.

4. Attempts by persons living in communist countries to obtain information of intelligence value from personnel by correspondence (including "Pen Pal" correspondence), questionnaires, "ham radio" activity, naval cachets (request to service postal covers), or other forms of communications.

Senior petty officers to whom information of the above nature becomes known must:

1. Instruct the reporting individual to take no action to exploit, apprehend, restrict, or stimulate further contact until appropriate guidance or instructions are received.
2. Report full details expeditiously to the commanding officer who should report his findings to the nearest Naval Investigative Service Officer.

Briefings and Debriefings

Periodic briefings must be held by all commands for personnel having access to classified information. These briefings must include special emphasis on the subjects discussed in Article 0305 of OpNav Instruction 5510.1 (Series).

In addition to the periodic security briefings, the former article also contains information on foreign travel briefings and potential hostage briefings.

Article 0306 of the Security Manual provides the necessary information for debriefing personnel who have had access to classified information and the security access has been terminated for any reason.

CLASSIFICATION

Information that will aid the senior petty officer in safeguarding classified material can be found in Articles 0405, 0406, 0423, 0424, 0426, 0432, and 0443 of the Security Manual. The contents of these articles should be familiar to all senior petty officers.

Regrading and Declassification

Overclassification of information and retention of information in classified status when it no longer requires such protection cause unnecessary delay and expense in handling and transmission, overburden stowage facilities and depreciate the classification system. Under such circumstances, security control is virtually impossible to enforce and to maintain. Therefore downgrading and declassification must be accomplished whenever possible.

A mandatory, continuing program based on a time schedule for automatically downgrading, and in most cases automatically declassifying documents originated within the Department of Defense has been established by the Secretary of Defense Determination of specific dates or passage of events that will provide early downgrading or declassification should be made as a matter of practice. When this is not possible, classified material must be categorized into one of the four groups described in the following paragraphs for automatic downgrading and declassification of classified information. Downgrading and declassification groups are as follows:

Group 1 Material

Material in this group is completely excluded from the automatic downgrading and declassification provisions either because it has been removed from such provision or because it contains information not subject to the classification jurisdiction of the Executive Branch of the U.S. Government.

Group 1 material may be downgraded or declassified only by the originating authority, or by an official higher in the same chain of command.

Group 2 Material

Material in this group is exempt from automatic downgrading and automatic declassification because it contains extremely sensitive information originally classified TOP SECRET or SECRET.

The authority for designating material as Group 2 is granted only to those officials empowered to exercise original TOP SECRET classification authority. This authority may not be delegated and must be exercised only when required in the interest of national security. It is intended that the number of Group 2 documents be kept to an absolute minimum.

Group 2 material may be downgraded or declassified only by the originating authority or by an official higher in the same chain of command.

Group 3 Material

Material in this group warrants some degree of classification for an indefinite period. Group 3 material is exempt from automatic declassification. Unless the originator specifies a shorter interval, they shall be downgraded automatically as follows:

1. TOP SECRET material will be downgraded to SECRET 12 years from date it was created and to CONFIDENTIAL 24 years from date it was created, and will remain CONFIDENTIAL.
2. SECRET material will be downgraded to CONFIDENTIAL in 12 years, and will remain CONFIDENTIAL.
3. CONFIDENTIAL material will remain classified.

Group 3 material may be declassified only by the originating authority or by an official higher in the same chain of command.

Group 4 Material

Group 4 material includes all classified material which does not qualify, or is not assigned to, one of the first three groups.

Group 4 material is automatically downgraded and declassified as follows:

1. TOP SECRET material will be downgraded to:

   a. SECRET 3 years from date it was created.
   b. CONFIDENTIAL 6 years from date it was created; and
   c. Declassified 12 years from the date it was created.

2. SECRET material will be downgraded to:

   a. CONFIDENTIAL 3 years from the date it was created; and
   b. Declassified 12 years from the date it was created.

3. CONFIDENTIAL material will be automatically declassified 12 years from the date it was created.

Each original and derivative classifying authority is similarly authorized to reclassify and declassify official information previously classified by virtue of his position. Such authority includes changing the downgrading and declassification group to which information may be initially assigned.

Custodians are authorized to reclassify and declassify classified information in accordance with the downgrading and declassification markings affixed to classified information. In the case of classified information received via a receipt or logbook signature system, the Classified Material Control Officer will be notified whenever a document has been remarked in accordance with this paragraph.

Higher authority in the chain of command or higher authority having primary cognizance over the subject matter involved must correct an erroneous classification which has been assigned by a subordinate, or downgrade or declassify information when such action is deemed appropriate.

When the interests of two or more commands are involved in the reclassification of information, coordination between such commands is required.

CHAPTER 3

MATERIAL CONTROL

A Chief or First Class Technician, especially if in a supervisory billet, will find himself increasingly involved in the details of supporting the man on the job. One of these detail areas is in the field of aviation supply.

Aviation supply personnel are vital members of the aircraft maintenance team; and the technician, as well as the other aviation maintenance ratings, must work in close harmony with them if successful teamwork is to be achieved. The team must work so that a flow of parts is maintained from the manufacturer to the man on the job—quite possibly a technician doing repair work on the other side of the world. A correct concept of supply's relationship to the entire organization is essential in the supervision of aircraft maintenance functions.

ORGANIZATION AND FUNCTION OF NAVAL SUPPLY

Prior to the establishment of the Aviation Supply Office (ASO), aircraft spares were bought by the naval bureaus, naval air stations, and the Naval Aircraft Factory as they were needed. This system, though efficient enough before World War II when aircraft component parts were few, was too loosely organized for the great expansion of the Navy's aircraft program that followed the fall of France in 1940.

ASO was established in 1941 under the technical control of BuAer and the management control of BuSandA. The function of ASO was the procurement, custody, and issuance of aeronautical spare parts and technical material.

Today, ASO supports approximately 8,500 aircraft. The aircraft have changed; the methods of controlling their spare-part support have changed. But ASO's mission today is the same as it was during World War II—to insure that the Navy's aircraft have the right parts, in the right quantities, in the right place, and at the right time. ASO is now under the technical control of the Naval Air Systems Command and the management control of the Naval Supply Systems Command.

RESPONSIBILITIES OF THE NAVAL MATERIAL COMMAND

The Chief of Naval Material (CNM) is responsible for providing the material support needs of the operating forces for equipment, weapons or weapons systems, materials, facilities, and supporting services. He also formulates and effectuates policies and methods of procurement, contracting, production of materials, and of procurement and contracting services throughout the Navy. CNM heads six principal subordinate commands. Two of these commands are concerned with aviation supply and are discussed below. (See fig. 3-1.)

Naval Supply Systems Command (NavSup)

NavSup is responsible for supply management policies and methods and provides ASO with the following:

1. Command guidance and supply system policy.
2. Operating funds for civilian salaries, office equipment and supplies, and travel.
3. Navy Stock Funds for financing procurement of consumable aeronautical spares.

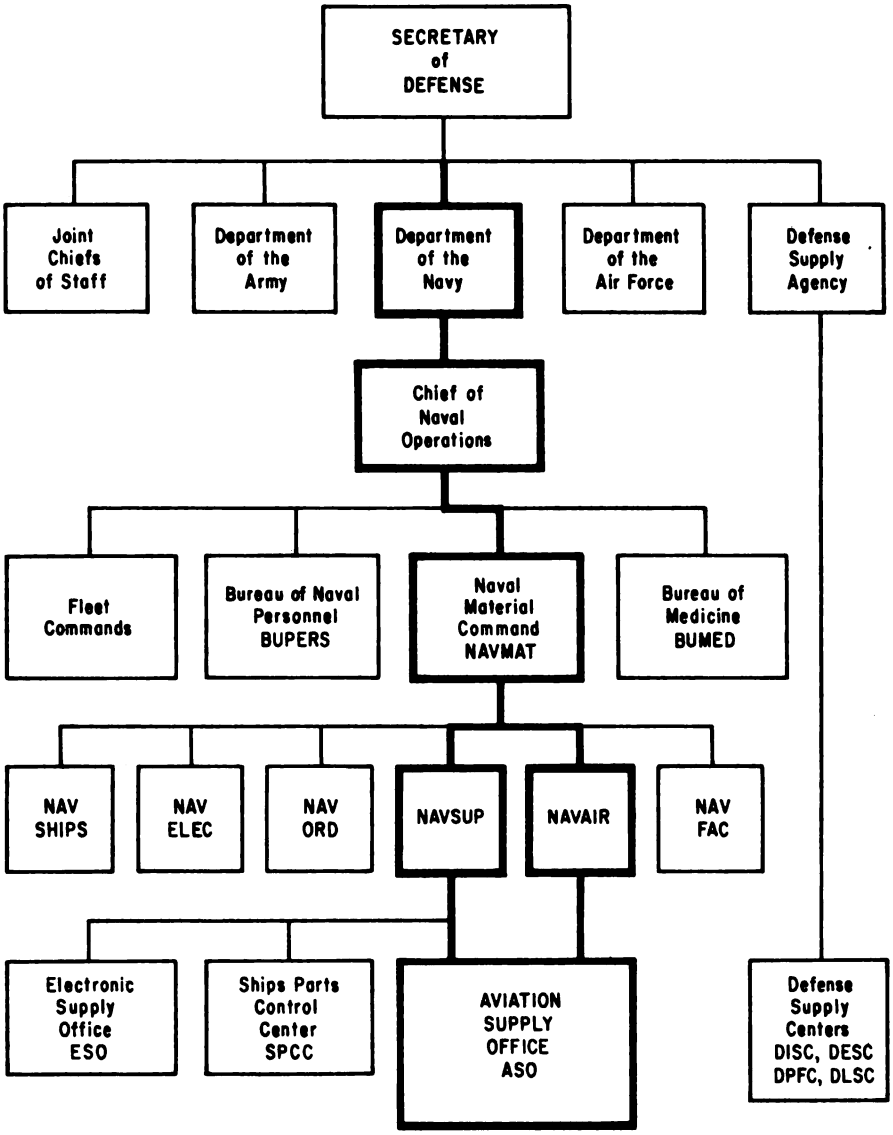

SECRETARY of DEFENSE
Joint Chiefs of Staff
Department of the Army
Department of the Navy
Department of the Air Force
Defense Supply Agency
Chief of Naval Operations
Fleet Commands
Bureau of Naval Personnel BUPERS
Naval Material Command NAVMAT
Bureau of Medicine BUMED
NAV SHIPS
NAV ELEC
NAV ORD
NAVSUP
NAVAIR
NAV FAC
Electronic Supply Office ESO
Ships Parts Control Center SPCC
AVIATION SUPPLY OFFICE ASO
Defense Supply Centers DISC, DESC DPFC, DLSC

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Figure 3-1.—ASO's relationship within the Department of Defense.

Naval Air Systems Command (NavAir)

NavAir is responsible for Navy and Marine Corps aircraft and airborne weapons systems and other aviation-related equipment, and the systems integration of aircraft weapon systems. NavAir provides ASO with the following:

1. Technical guidance.
2. Weapons systems program data.
3. Funds for the procurement of aeronautical repairables.

Aviation Supply Office (ASO)

The primary Navy inventory control point (ICP) responsible for material support of the Naval Aviation Maintenance Program (NAMP) with respect to technical aviation material is ASO. Technical aviation material consists of spares and spare parts for aircraft, engines, avionic, electrical, accessory, and safety equipments; Ground Support Equipment (common and peculiar); and aeronautical photographic and meteorological equipment. The responsibilities of ASO include, but are not limited to, the following:

1. The determination of aviation requirements in both range and depth. This responsibility includes the conducting and coordinating of provisioning conferences and the identification and transfer of items to be managed by the Defense Supply Agency (DSA) and other cognizant ICP's.
2. The budgeting and funding of all assigned aviation material requirements.
3. The procurement of material directly from industry or via other government agencies.
4. The allocation of NavAirSysCom procured materials to stock points; the distribution of material to fill replenishment stock requirements; and the referral of requisitions to stock points to meet end use requirements.
5. The disposal of materials that are in excess to system requirements.
6. The maintenance of aeronautical spares and spare parts catalog. The function includes the obtaining of FSN (Federal Stock Numbers) from the Defense Logistics Systems Center (DLSC).
7. The determination of system asset rework requirements of repairable components to be processed by Navy or commercial rework facilities.
8. The development, issuance, and updating of initial outfitting, allowance, and load lists applicable to the NAMP.

APPROPRIATIONS

At one time or another, almost everyone has had the frustrating experience of not being able to draw from supply some item that he thought necessary to have immediately; the usual reason given being, "We don't have any money left." It takes only a short time to realize that the Navy does not operate with unlimited funds. This section and the following section, titled "Funding," are presented to further an understanding of the system whereby funds are made available at the user activity level for operating expenses.

The main money pool of the government is the General Fund of the Treasury. Funds come into the General Fund from such sources as income taxes, excise taxes, import-export taxes, etc. The only way for money to be expended from the General Fund is by congressional action, which has to be approved by the President. A bill passed by Congress which authorizes the expenditure of funds from the General Fund is called an appropriation.

An estimate of the amount of money required for the operation of the Defense Department during a given fiscal year is prepared by Department of Defense fiscal experts well in advance of the beginning of the fiscal year. The Congress studies the proposed budget in the light of world affairs, the current domestic economy, and such other considerations as they see fit, then acts upon it. They may increase the amount requested, decrease it, or pass it as submitted. After presidential action is completed, the money is made available to the Department of Defense to be spent during a specified year. This is known as an "annual" or "1-year" appropriation.

Congress and the President may also approve "no-year" appropriations for special projects such as large construction over an unspecified length of time. Another form of appropriation is the "multiple-year" appropriation for projects which will be completed in a predictable length of time. An example of this type of appropriation might be the money appropriated to cover the expenses of the NROTC college programs for the next 4 years.

The appropriation by which the AQ is most affected is the current year appropriation. After the appropriation or expenditure authorization is received in the Department of Defense, it is prorated among the services as a percentage of their previously submitted budget estimates. The Navy's share is prorated among the various bureaus and commands in essentially the same manner; that is, as a percentage of their estimated requirements for the coming fiscal year. The money to be spent for naval aviation is made available to CNO. Here, part of the money is allocated to ASO for the purchase of aircraft spare parts in quantities which past usage data has indicated will probably be sufficient for the coming year. These spare parts are furnished to the operating activities at no cost, since their usage has been anticipated and the items paid for in advance. The account from which money was spent to buy these items is known as the Appropriation Purchase Account (APA). Material received in the user activities from this account is known as APA material.

Another part of the CNO funds is made available to the operating activities in the form of operating funds.

FUNDING

All aviation activities responsible for operating aircraft are provided funds for certain operational and organizational maintenance expenses under the O&MN (Operations and Maintenance, Navy) appropriation subhead 1911 or in the case of the Naval Air Reserve, O&MN appropriation subhead 1912. These funds are intended to provide for all fundable supplies in the operation of aircraft and for fundable materials used in the organizational maintenance of assigned aircraft. It is intended that funds provided to intermediate maintenance levels will be used for the assigned maintenance within their scope, and such funds are not to be used to procure this service from other naval activities. The funds are for fundable supplies only (labor is performed by military personnel and not a fundable charge). Housekeeping, administrative, and other similar expenses are to be provided by the supporting ship or station and are not chargeable to these funds.

Maintenance Funds

Funds used for the operation and maintenance of naval aircraft and related equipment are defined as maintenance funds. Maintenance managers must familiarize themselves with these funds and their respective purposes, since responsibility must be commensurate with funding.

Aircraft Operating Funds

Aircraft operating funds finance the following:

1. Aviation fuels and lubricants (POL) consumed in aircraft.
2. Flight clothing and operational equipment authorized in the NavAir 0035QH-2 allowance list, with the exception of exchangeable aeronautical equipment, such as life vests, rafts, parachutes, etc. (These exceptions are financed by Aviation Maintenance funds.)
3. Squadron administrative (office) consumable supplies.
4. Aerial film used in aircraft.
5. Flight deck/safety shoes used by squadron personnel in the readiness, launch, and recovery of aircraft.
6. Initial issue of unit identification marks for newly reporting personnel.
7. Liquid and breathing oxygen used during flight operations by both the aircraft system and pilot.
8. Forms and publications (Cog symbol II) and the printing and reproduction thereof.
9. All reimbursable maintenance material procured when located at other than the parent supporting ship and/or station, including APA material procured from other Government agencies or commercial concerns, by aircraft on extended flights. (This does not include aircraft maintenance funds, which are furnished by the Operations Maintenance Division of the station at which the aircraft has landed.)

Air Staff Administration and Operations Funds

Air Staff Administration and Operations funds finance the following:

1. Administrative office supplies for daily operations.
2. Office equipment and accessories not classified as investment items.
3. Rental of office machines on a contract basis.
4. Special incentive awards for staff or aviation units. These awards should contribute towards motivation and a high degree of morale and be purchased on a minimum basis.
5. Special flag office accessory items.

Aviation Outfitting Funds

Aviation outfitting funds are made available to finance the initial outfitting of all allowance list and Table of Basic Allowances (TBA) equipment issued to Navy squadrons and deployable aircraft.

1. Initial outfitting is defined as:

   a. Initial issue of any item or organizational property to a squadron or unit during an interval from the time of commissioning, terminating 6 months after the date of commissioning.
   b. Initial issue of allowance list and TBA items during an interval from date of allowance list change, terminating 6 months after the date of the allowance list change.
   c. Initial issue of increased allowed quantities during an interval from the date of authorization for the increased quantity, terminating 6 months after the date of the authorization.

2. Aviation outfitting funds do not support any additional required maintenance support tools and equipment not specifically designated as organizational property.

Fleet Outfitting Equipment Funds

Fleet outfitting equipment funds finance the following:

1. Initial issue of special fleet outfittings and reoutfitting of equipment (organizational property) as authorized and directed by the type commander through the administrative commanders.
2. Replacement of the above items if authorized by the type commander.

Temporary Additional Duty Travel Funds

Temporary Additional Duty (TAD) travel funds are provided to finance temporary additional duty travel expenses for personnel attached to type commander aircraft squadrons and units. Expenses financed include the following:

1. Returnable school quotas for aviation unit personnel.
2. Aviation crew rotation.
3. Inspection, logistic support, and other administrative travel by fleet aviation unit personnel.
4. Emergency quarters while on extended flight.

Aviation Maintenance Funds

Aviation maintenance funds finance the cost of NSA (Navy Stock Account), DSA (Defense Supply Agency), GSA (General Services Administration), and open-purchase materials and supplies consumed in the performance of aviation organizational and intermediate maintenance, including the costs of the following:

1. Technical repair parts, common hardware, lubricants, cleaning agents, cutting compounds, metals, etc., incorporated into or expended in the performance of aviation maintenance of aircraft, aircraft engines, aeronautical components and subassemblies, GSE, and consumable IMRL items.
2. Fuels and lubricants (POL) used in the test, check, and runup of engine or components.
3. Rag or red towel service and cleaning.
4. Preexpended, consumable maintenance material.
5. Replacement of expendable/consumable allowance list items (Material Accountability

and Recoverability Codes B and C), including IMRL items.

Fleet Funding

Appropriations for operation and maintenance of the Navy are allocated to each fleet commander for financing supplies and equipage requirements. Fleet commanders are responsible for the administration of and accounting for funds allocated to them and must maintain official accounting records and submit reports as required. Fleet commanders issue an allotment to each type commander to finance supplies and equipage requirements of all ships and flags under his command. (Under the resources management system, this grant is called the expense operating budget.)

A type commander grants authority to ships and commands under his control to cite his allotment for materials and for certain services. This "obligational authority" is referred to as operational target or OPTAR.

OPTAR Funds

OPTAR funds are provided each command by the type commander and are controlled by the commanding officer with the supply officer maintaining an accurate record of command expenditures.

Senior AQ's aboard ship should be concerned with OPTAR in keeping supply records on a divisional level. Normally aviation squadron AQ's are not required to keep records of OPTAR expenditures; this service is performed by the material control division for the entire squadron.

Military Requirements for Petty Officer 1 & C, NavPers 10057-C, Chapter 5 (Supply) contains additional information on supply and funding.

DISTRIBUTION SYSTEM

The aviation supply distribution system consists of reserve stock points, primary stock points, secondary stock points, and satellites. These are discussed briefly in the following paragraphs.

1. Reserve Stock Points carry reserve and backup stock for the aviation supply system at reserve stock points. The range and quantity of stock are determined by the Aviation Supply Office. Reserve stock points provide storage facilities for bulk material.
2. Primary Stock Points carry stock for their own consumption. They may be designated as support activities for secondary stock points, for fleet units, and/or yard and district craft in the area.
3. Secondary stock points carry stock for their own consumption as well as stock for aircraft and assigned yard and district craft.
4. Satellites are aviation activities which are dependent for support on a primary or secondary stock point. Satellites are usually minor activities and normally receive their supply support on a retail issue outlet basis.

As far as the consumers are concerned, they may be assigned to any of the primary, secondary, or satellite stock points for supply support. The same basic principles will affect your supply support.

MATERIAL IDENTIFICATION

As part of the aviation maintenance team, the technician will be working closely with the aviation storekeepers in keeping aircraft in an "up" status. In order to obtain replacement parts as rapidly as possible, the technician must know how to determine the source of supply of different items. For example, many hours may be wasted trying to find that the item is to be manufactured within the activity. Also, it is important to know the correct stock number and cognizance symbols used to requisition items from supply.

The cataloging system developed by the Department of Defense is such that it identifies with one name and stock number any item of supply that is carried in any or all government agencies. In the procurement of material it is normally necessary to identify your material requirement in the medium understandable to the supply system.

FEDERAL STOCK NUMBERS

Prior to 1952 each of the services had its own numbering system for identifying, cataloging, stocking, and issuing items of military supply. It was not unheard of that one service would be negotiating on the open market for an item that was held in surplus by another service under its own stock number. This confusion resulted in the passage in 1952 of the Defense Cataloging Standardization Act.

The implementation of this Act has resulted in a reduction of item duplication between the services by providing for one Federal Stock Number (FSN) for each item, regardless of the use of the item or the using activity.

Coded Federal Stock Number

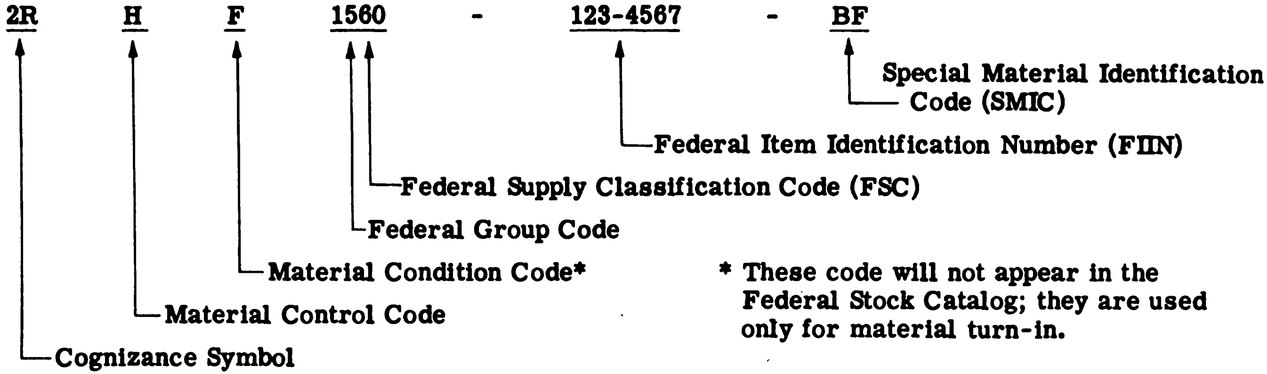
The federal stock number consists of an 11-digit number. The Aviation Supply Office uses federal stock numbers with prefixes composed of one, two, or three symbols, and suffixes composed of four characters which may be all letters or a combination of letters and numbers. When the prefixes and suffixes are used, the federal stock number becomes a coded federal stock number. A coded federal stock number and its breakdown is shown in table 3-1.

If a 1-symbol prefix is used, it designates the command or office having control or cognizance of a particular item. Listed below are some of the more common cognizance symbols, together with the type material controlled and the name of the cognizant command or office.

SYMBOL	COGNIZANT ACTIVITY	MATERIAL CONTROLLED
2R	Aviation Supply Office	Aeronautical material
2V	Naval Air Systems Command	Major aeronautical equipment
1I	Navy Supply Depot, Philadelphia	Forms
0I	Navy Supply Depot, Philadelphia	Publications

Many variations of coded stock numbers will be encountered in field maintenance work. These variations indicate material management responsibilities for the item; flag certain items as recoverable, consumable, high value, etc.; and identify the condition of the material if it is not

Table 3-1. —Breakdown of a coded Federal stock number.


2R
H
F
1560
-
123-4567
-
BF
Special Material Identification Code (SMIC)
Federal Item Identification Number (FIIN)
Federal Supply Classification Code (FSC)
Federal Group Code
Material Condition Code*
Material Control Code
Cognizance Symbol

* These code will not appear in the Federal Stock Catalog; they are used only for material turn-in.

ready for issue. Some of the more common codes that a technician is likely to encounter include the following:

RH—a recoverable aeronautical component of high value.

2RHF—a recoverable aeronautical component of high value that is not ready for issue.

Because the variety of codes is so extensive and the trend to single service management of items has caused so many changes in recent years, a list of codes that might be prefixed or suffixed to a stock number would not be appropriate for this manual. The primary things to keep in mind are that the basic stock number, consisting of three groups of numerals, identifies the item from a technical point of view and that the other codes identify material management characteristics.

With the advent of the single manager concept, many items formally carried in the individual Navy Stock Lists are cataloged in the Federal Supply Catalog for General Supplies. The complete catalog consists of many sections and is arranged by federal supply classification class.

MATERIAL IDENTIFICATION AIDS

There may be times when a part or some technical material is needed and the stock number is unknown. At other times some material may be on hand and its identity is not positively known. A knowledge of the several methods by which material may be identified is very helpful in speeding the completion of a maintenance task. There are many ways in which material may be identified. Certain data may be available which does not identify an item but may lead to positive identification. An aircraft part has a part number. The part number may be looked up in the IPB and identified by nomenclature and often by the stock number. If the stock number is not furnished in the IPB, it may be found by referring to the Cross-Reference Section C0006 of the Navy Stock List of ASO.

Some equipments have attached nameplates which provide such information as the manufacturer's name, make or model number, serial number, size, voltage, phase, etc. Identification data taken from the nameplate of the old part can be very helpful in procuring a replacement.

When only the description of the item is known, the best source for identification is the descriptive sections of the various Navy Stock Lists.

Various publications used in identifying material are described in the following paragraphs.

Illustrated Parts Breakdown (IPB)

The IPB continues to be the most important source for obtaining information necessary to order specific aircraft and equipment parts. Properly used, the IPB will provide reference information necessary to identify a part number to a specific model aircraft and in some cases provide interchangeability data that can be utilized when the prime item requested is not in stock.

IPB's are compiled by the manufacturer for each aircraft model in naval use. IPB's, as discussed here, encompass IPB's for aircraft, IPB's for aircraft engines, and IPB's for individual accessories and equipments.

Although slight variations in format exist among the various IPB's, each normally includes the following major sections:

I. TABLE OF CONTENTS—This section shows the breakdown of the catalog into sections and furnishes a cross-reference between the various assemblies and figures where they are illustrated. The section also cross-references assemblies and pages where they are broken down into subassemblies and parts.

II. INTRODUCTION—This section includes general information and instructions for using the publication. Because variations between IPB's do exist, this section should be referred to prior to using an IPB with which you are not thoroughly familiar.

III. GROUP ASSEMBLY PARTS LIST—This section is the main text of the publication. It consists of a series of illustrations and parts lists in which all parts of the aircraft/engine/equipment are shown in assembly breakdown order. The illustrations and parts lists are keyed to each other by means of figure and index numbers. Each assembly included in the parts lists is followed immediately by its component parts properly indented to show their relationship to the assembly. The group assembly parts list is subdivided into groups such as wing group, tail group, and fuselage.

IV. NUMERICAL INDEX–This section lists all parts in alphanumerical order, and each part is cross-referenced to the figure and index number where it is illustrated. This list also shows the official source code of each part listed in the applicable IPB.

The MASTER LOCATOR INDEX replaces the numerical index for some aircraft IPB volumes. The master locator index is used to locate the manual in which a part number will appear when only the part number is known. The part numbers are listed in alphanumerical order. The manual number appearing in the manual No. column refers to the last dash number of the NavAir manual number. For example, if the number shown in the manual No. column of the A-6 master locator index is 8, complete information on the part will be found in IPB volume, NA 01-85-ADA-4-8. The master locator index, unlike the numerical index, does not always provide source, maintenance, and recoverability information.

If a failed part is one that was installed as a result of a technical directive, the part number may not appear in the IPB. The index manual for the IPB volumes will include a list of directives which have been incorporated into the IPB's. For information on parts where the directive has not been incorporated, the directive may provide the necessary information for ordering a replacement item.

The REFERENCE DESIGNATOR INDEX, normally the last section of the IPB, is a listing of reference designators (C104, R603, K202, etc.) used on the electrical and electronic wiring diagrams. The reference designator index will aid in the location of parts where only the reference designation number is known.

AERONAUTICAL ALLOWANCE LISTS

This title is inclusive of publications identified as Allowance Lists (except advanced base lists), Initial Outfitting Lists, and Tables of Basic Allowances.

PURPOSE AND ORIGIN

Aeronautical Allowance Lists are prepared by the Naval Air Systems Command or by activities as designated and directed by this command. These lists contain the following:

1. The equipment and material (both consumable and nonconsumable) necessary to outfit and maintain units of the aeronautical organization in a condition of material readiness.
2. Substantially all items used with sufficient frequency to justify their issuance to all activities maintaining aircraft or equipment for which the lists are designed.
3. Information concerning stock number, nomenclature, interchangeability, and supersedures.
4. A set of detailed instructions for the application and utilization of the publication.
5. A table of logistic data showing the total weight and cube of all material contained in the list.

In the final analysis, Aeronautical Allowance Lists are lists of equipment and material determined from known or estimated requirements as necessary to place and maintain aeronautical activities in a condition of material readiness.

Aeronautical Allowance Lists are reissued in accordance with reissue cycles established by the Naval Air Systems Command, or sooner, if required. Interim to reissues, the lists are maintained current by letters and by the issuance of Change Pages and Change Bulletins. Change Bulletins, which are official publications, are issued by ASO on a monthly basis, are numbered in consecutive numerical sequence within each calendar year, and are distributed to holders of allowance lists. For checkoff purposes, a Change Bulletin Index is also published by ASO semiannually and distributed in the same manner as the Change Bulletins.

Allowance lists indicate the range and quantities of support equipment considered necessary for maintenance support of assigned and/or supported aircraft. Generally, these items are in-use items required for daily or continual use, such as handtools and avionics test equipment.

Initial outfitting lists (IOL's) are publications which indicate the range and quantities of maintenance spare parts considered necessary to support various aeronautical articles. This material is provided to vessels or activities and is firm only at the time of initial outfitting. Increases and decreases in both range and/or quantities of material are based upon the experience (demand history) of each activity concerned. Each series list is designed to support an aircraft, electronic equipment, or some other aeronautical article. The allowances of material are established for various articles for a 90-day period. All items capable of replacement by a maintenance activity are not listed, but rather, only those that are expected to be used at least once in 90 days.

Publications listing equipment and material required for performance of specific functions are known as Tables of Basic Allowance. They contain both shop equipment and common supporting spare parts. They cover allowances of tools and equipment required for use by such activities as Fleet Marine Force squadrons and guided missile activities.

Initial Outfitting Lists and Allowance Lists are identified by the publication number NavAir 00-35Q, series while Tables of Basic Allowance are identified by the publication number NavAir 00-35T series. Those allowance lists of primary interest are listed in the following paragraphs:

Section "A" Initial Outfitting List (NavAir 00-35QA-1)–

Lists standard aeronautical and Navy stock account material common to the designated aircraft classes.

Section "B" Initial Outfitting List (NavAir 00-35QB)–

Series lists peculiar maintenance parts (airframe, engine, accessories) required for support of specific aircraft models. (Includes lists for certain target aircraft and guided missiles.)

Section "BR" Initial Outfitting List (NavAir 00-35QBR)–

Series lists peculiar maintenance parts (airframe, engine, accessories, electronics) required for support of concerned target aircraft model, drone helicopter, or guided missile. (Prepared in lieu of separate Section "B" for airframe, engine, accessories, and Section "R" lists for electronic parts due to limited installation of electronic equipment.)

Section "G" Allowance List (NavAir 00-35 QG)–

Series lists general maintenance support equipment and handtools required for intermediate and organizational levels of maintenance support of aircraft.

Section "R" Initial Outfitting List (NavAir 00-35 QR-4)–

Lists general aeronautical electronics material common to and required for maintenance of avionics equipment and systems.

Section "R" Allowance List (NavAir 00-35QR-5)–

Lists avionics support equipments required for maintenance of installed avionics equipment and systems. A confidential supplement to NavAir 00-35QR-5 is issued as a separate publication.

Section "R" Initial Outfitting List (NavAir 00-35QR-5A)–

Lists peculiar parts required for maintenance of electronic test equipments authorized in NavAir 00-35QR-5.

Section "R" Initial Outfitting List (NavAir 00-35QR-6)–

Lists aeronautical electronic accessories common to designated aircraft classes.

Section "R" Initial Outfitting List (NavAir 00-35 QR-7)–

Lists electron tubes required in the maintenance of aeronautical equipment utilizing such tubes.

Section "R" Initial Outfitting List (NavAir 00-35QR-30)–

Series lists peculiar parts, spare components, assemblies, and subassemblies required for maintenance of appropriate aeronautical electronic equipments.

Section "T" Allowance List (NavAir 00-35QT)–

Series lists special maintenance support equipment required for intermediate and organizational levels of maintenance of airframes, powerplants, accessories, avionics equipment, and/or aircraft model to which the list applies.

Section "X" Initial Outfitting Allowance List (NavAir 00-35QX-30)–

Series lists peculiar parts, spare components, assemblies, and subassemblies required for maintenance of the armament, fire control, instrument, or electrical system to which the list applies.

Section "Z" Initial Outfitting List (NavAir 00-35QZ)–

Series lists peculiar parts for electric powerplants, special and general aircraft, and guided missile support equipment.

Weapon Equipment Lists

Equipment parts lists catalog material according to the type of aircraft or equipment it is designed for rather than what it is. ASO is in the process of developing a Weapon Equipment List (WEL) for each aircraft type. For example, WEL 0076 and WEL 0086 contain lists of repairable assemblies, supporting repair parts, attaching parts, loose equipment, and accessories for the A-7A and the A-4 (Series) aircraft, respectively.

A WEL contains a cross reference listing from the manufacturers part number to the federal stock number. The WEL is a comprehensive multivolume publication containing all the management data necessary for identification and procurement of items for the aircraft type covered. It also contains a list of allowance lists, major avionics equipment, and technical manuals applicable to the aircraft and a section containing explanations of the various codes and information on how to use the publication.

Descriptive/Identification Lists and Illustrated Shipboard Shopping Guides

Descriptive type catalogs or Identification Lists (IL's) are available on all Federal Supply Classification (FSC) group materials. These lists catalog material by what it is rather than by how it is used. These catalogs are similar to the Sears-Roebuck type catalogs, which have a comprehensive alphabetical index, group like items together, and thoroughly describe the items (size, weight, composition, etc.).

The Illustrated Shipboard Shopping Guides (ISSG) are similar in many ways to the IL's. They are designed to assist fleet personnel in identifying those items of supply not normally related to a part number or reference number to an FSN. They also provide assistance in determining substitute items by virtue of illustrations, specifications, and narrative descriptions from which data can be compared.

The ISSG is a multivolume publication consisting of an introduction and master index plus a number of individual sections applicable to material in the specific federal supply classes or groups. The master index provides an alphabetical sequence listing of all item names included in the ISSG, with reference to the individual sections (FSC group or class) wherein they appear.

SOURCE AND ACCOUNTABILITY CODES

Source Codes

Source codes are symbols which indicate the source of supply for an item required to maintain or repair a component part of an aircraft. The source code for each item is listed in the Numerical Index of the IPB and in the Allowance List. Specifically, these codes indicate whether the item is to be requisitioned from the supply system; to be manufactured; to be obtained from salvage; not to be installed; or, due to failure, is in need of complete overhaul or retirement of the assembly or equipment from service.

A complete list and definition of source codes are presented in the introductory pages of the IPB or Allowance List. The following are examples of source codes:

SOURCE CODE P1 is applied to items which are purchased in view of known or anticipated usage and which are impractical or uneconomical for military service manufacture.

SOURCE CODE MO is assigned to items to be manufactured at the organizational level of maintenance.

SOURCE CODE AF applies to items to be assembled at intermediate maintenance levels afloat.

SOURCE CODE NN applies to items designated to be purchased locally and not stocked in the Navy supply system.

Accountability Codes

Accounting for material does not cease when it is withdrawn from the supply department. It is at this point that the accounting responsibility passes to the applicable maintenance personnel.

The accountability codes used in allowance lists and most IPB's are known as Material Accountability Recoverability Codes (MARC's). MARC's are assigned only to aeronautical provisioned items to reflect the accountability, recoverability, and repair policy determined for an item of equipment of material required for the maintenance, repair, or rework of an end item. MARC is a system whereby a letter of the alphabet is used as a guidepost by personnel working with aviation material. This system helps personnel to determine the proper method of the following:

1. Requisitioning material with regard to inventory control and fiscal accounting procedures.
2. Accounting for material while in use.
3. Turn-in or disposition of material.
4. Repair or overhaul.

The following list defines the various material accountability codes.

B — Exchange Consumables. Code B is applied to items which are consumable or expendable but normally require item-for-item exchange for replacement. Such items may contain precious metals, may be highly pilferable, or may be high cost items.

C — Consumables. Code C is applied to all other consumable or expendable items which do not require item-for-item exchange for replacement.

D — Equipage, Support Type. Code D is applied to end items of support equipment which are economical and practical to repair on a scheduled basis through a major rework activity. Code D items are maintained on a custodial basis and normally require item-for-item exchange for replacement.

E — Equipage, Locally Repairable, Support Type. Code E is applied to end items of support equipment which are to be repaired locally by the using or fleet support activity within their assigned maintenance responsibility. Code E items are maintained on a custody basis and normally require item-for-item exchange for replacement.

R — Equipage. Code R is applied to repairable (except end items of support equipment) items which are economical and practical to repair on a programed basis through a major rework activity. Code R items are maintained on a custody basis in some cases, depending upon the use of the item. These items normally require item-for-item exchange for replacement.

L — Equipage, Locally Repairable. Code L is applied to repairable (except end items of support equipment) items which are to be repaired locally by the using or fleet support activity within their assigned maintenance responsibility. Code L items are maintained on a custody basis in some cases, depending on the use of the item. They will normally require item-for-item exchange for replacement.

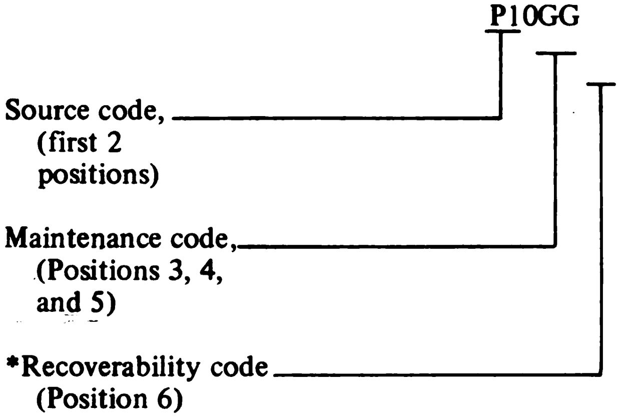
Source, Maintenance, and Recoverability Codes (SM & R)

A six-digit SM & R code will eventually replace the source and MARC's now being used. The actual code used to identify the source will remain the same.

Source, maintenance, and recoverability codes are used in the various IPB's and allowance lists to identify the source of spares, repair parts, and items of support equipment and the levels of maintenance authorized to maintain, repair, overhaul, or condemn them.

The coding controls the range of parts procured to support new equipments and expedite the maintenance, repair, and overhaul of aeronautical equipments by providing maintenance and supply personnel with the necessary information relative to the source of supply and, where applicable, the maintenance implications and recoverability status of items.

The SM & R code format is composed of three parts—a two-position source code, a three-position maintenance code, and a one-position recoverability code. The following is an example of a complete SM & R code.


P10GG
Source code, (first 2 positions)
Maintenance code, (Positions 3, 4, and 5)
*Recoverability code (Position 6)

*This code is currently not used within the Navy and is left blank in the format. When later assigned they will show actions required to reclaim or dispose of the item.

The source code (first 2 positions) indicates the means of acquiring the item.

The third-position maintenance code indicates to maintenance and supply personnel the lowest level of maintenance authorized to remove and replace the item.

The fourth-position maintenance code indicates the lowest maintenance level authorized to accomplish repair, overhaul, or assembly of the item. Code Z in this position indicates that no repair is expected to be made at any level.

The fifth-position maintenance code indicates the lowest maintenance level authorized to condemn the items when repair or overhaul at this level or higher level is not economically or militarily justified.

The recoverability code indicated in the sixth position indicates special instructions on reclamation or disposition actions required on the item. Use of this position is temporarily being held in abeyance pending greater Department of Defense standardization of the codes. Material accountability/recoverability codes (MARC's) are to be used separately pending approval of these codes for inclusion in the SM & R code format.

MATERIAL REQUISITIONING

Maintenance personnel are apt to encounter a variety of local requisitioning channels; all designed to present a demand for an item to the supporting supply department. Assigned levels of maintenance, geographical location of shops relative to supply facilities, and mission of activities requiring support all influence the local requisitioning channels. Local instructions normally promulgate detailed procedures for submitting your demand to the appropriate supply point.

SUPPLY ACTIVITY

The mission of the supply activity is to support the operational and maintenance efforts of the activity/ship. Stocks of aviation oriented material carried are tailored and replenished to this end. Positioning, replenishment, and control of stocks of material in maintenance areas are carried out as a result of joint decisions by the Supply and Maintenance Officers concerned. They determine the range, depth, and related procedures. The Navy Maintenance and Material Management System (Aviation) requires that the cost of material used in maintenance be determined and accumulated in such manner and detail that weapons system costs can be measured. Usage is finely defined as to stock number, within component, within equipment/weapon/aircraft, in a particular squadron, located in a specific operational area, at a definite point in time. These data are used as an inventory management tool to determine geographic and strategic distribution of stock of material. In addition, the data will be invaluable in establishing the material portions of work standards in maintenance.

Supply Support Center

Maintenance organizations have one single point of contact with the supporting supply activity. This single supply contact point is the Supply Support Center (SSC) which responds to all material requirements of the maintenance organizations. The SSC is an internal organization of the local supply activity. It is made up of two sections—the Supply Response Section (SRS) and the Component Control Section (CCS).

Supply support is available consistent with the operating hours of the maintenance activities supported. If maintenance is being performed 24 hours a day, then supply support is available 24 hours a day.

The supply support center maintains rotatable pool material which consists of repairable ready-for-issue items reserved primarily to satisfy the requirements of organizational level maintenance. Items maintained in the pool are capable of being repaired by the local intermediate maintenance activity, have application relationship to weapon systems supported by local intermediate maintenance activities, and have an average organizational maintenance level removal rate of at least one per month. Defective components are turned in to intermediate level maintenance for repair. The defective components repaired to an RFI condition are then returned to the rotatable pool to replace the components previously issued.

Low value, fast moving consumable items are preexpended from supply. Such materials are located in the maintenance area. The establishment, maintenance, and replenishment of preexpended bins are the responsibility of the supply organization.

SUPPLY RESPONSE SECTION.–The Supply Response Section (SRS) is responsible for preparing all necessary requisitions (DD Form 1348) and related documents required to obtain material for local maintenance use in direct support of weapon system maintenance. The maintenance organization verbally notifies the supply organization of the need for such material. When material is available locally, the time frame for processing and delivery is as follows:

Priority	Process/Delivery Time
1-3	1 hour (NORS/NFE)
4-8	2 hours
9-20	24 hours

Otherwise, the time frames as noted in table 3-2 will apply.

The SRS is responsible for receipt, storage, and issuance of all ready-for-issue pool components. It is responsible for physical delivery of RFI material to maintenance organizations, and the pickup of defective components from the organizational maintenance activity and subsequent delivery to the intermediate maintenance activity. Actual maintenance personnel are not

Table 3-2.—Processing time frames.

Issue group	Issue priority designator range	Supply source processing	CONUS on station time	Overseas on station time
1	1-3	24 hours 24-hour day 7-day workweek	120 hours	168 hours
2	4-8	72 hours 24-hour day 7-day workweek	8 days	15 days
3	9-15	10 days 8-hour day 5-day workweek	20 days	45 days
4	16-20	12 days 8-hour day 5-day workweek	30 days	60 days

involved in the physical movement of material between organizations.

This section also performs technical research in regard to completion of requisition documents as well as determining the status of outstanding requisitions and relaying this status to the customer upon request.

COMPONENT CONTROL SECTION.– The Component Control Section (CCS) accounts for all components being processed in the intermediate maintenance activities. This section also maintains records on the status of all rotatable pool components.

MATERIAL CONTROL DIVISION

The material control division at the organizational level is responsible for providing support and services to the production divisions as follows:

1. Requisition and expedite materials required to support the command.
2. Initiate surveys in the event of loss, damage, or destruction of accountable material/equipment.
3. Verify NORS (Not Operationally Ready Supply) requisitions.
4. Maintain accountability of material authorized by the allowance lists, IMRL's, etc.
5. Establish pickup and delivery points for material.
6. Maintain the material control register or facsimile.
7. Perform cost and allotment accounting.
8. Maintain aircraft inventory logs.
9. Pass all requirements for material required for direct support of weapon system maintenance to the SSC. A Material Control Register is maintained for these items.
10. Prepare documents for material required for indirect support of weapon systems maintenance. Examples of materials for which documents are to be prepared are aviation fuels and lube oils, rags, and flight jackets. A separate requisition record log is maintained for these items.
11. Maintain liaison with the supporting SSC on maintenance material matters to insure that material needs of the organization are satisfied.
12. Furnish technical advice and information to the supply activity on the identity and quantity of supplies, spare parts, and materials, required for maintenance actions.
13. Establish procedures to insure the periodic inventory of tools and the adequate accountability of material and equipment on custody to the cognizant organization.
14. Keep maintenance control advised of the overall supply situation as it affects the activity.

Material control is responsible for the coordination of material ordering, receipt, and delivery. This is done in such a manner as to insure that the correct material is ordered and that it reaches the work center within the specified time frame.

MATERIAL CONTROL REGISTER

The Material Control Register is used by material control to record all materials requested from the supply support center in direct support of weapon system maintenance. Space is provided to record essential information considered necessary to monitor OPTAR funds. This information includes part number, priority, quantity, price, date, time ordered, and date and time received. Maintenance control uses the time ordered and time received to help determine NORS time used in fulfilling readiness reporting requirements.

When a defective repairable item is turned in, the following forms are required; copies two, three, and four of the multicopy MAF and the Schedule Removal Component Form, OpNav 4790/27A, when applicable. The supply department uses copy two of the MAF for bookkeeping purposes. Copies three and four of the MAF accompany the item to the AIMD. When repair is completed by the AIMD, copy four of the MAF is attached to the RFI item and the item is returned to the supply system.

If material being turned in is no longer required and is RFI, a Single Line Item Release/Receipt Document (DD 1348-1) is submitted with the item. RFI means ready for issue in all respects–preservation still intact and item in original or reusable container with seals unbroken.

MILSTRIP

The Military Standard Requisitioning and Issue Procedure (MILSTRIP) and Uniform Material Issue Priority System were developed by the Department of Defense to provide a common supply language and more effective supply system operations within the military establishment. This system standardizes forms, formats, codes, procedures, and the priority system.

MILSTRIP employs two forms for the requisitioning and issuing of material. The Single Line Item Requisition Document (Form DD 1348) is the basic request document submitted to the applicable supply echelon for material requirements. The issue document is the Single Line Item Release/Receipt Document (Form DD 1348-1). Form DD 1348-1 is also used to return RFI material to the supply system. These forms will be prepared by the Supply Response Section of supply for all material requested in direct support of weapon system maintenance and by the material control division for material requested in indirect support of weapon system maintenance.

Uniform Material Movement and Issue Priority System (UMMIPS)

In this system, the priority designator is determined by a combination of factors which relate the military importance of the requisitioner (force/activity designator) and the urgency of need or end use (indicated by an urgency-of-need designator). The force/activity designator (a roman numeral I-V) is assigned by the Joint Chiefs of Staff (JCS), Chief of Naval Operations (CNO), and Navy commanders. The urgency-of-need designator (an alphabetical letter) is determined by the requisitioning activity, with certain exceptions. These two factors will enable the requisitioning activity to determine the UMMIPS priority designator (arabic numeral).

The twenty priority designators provided in UMMIPS have been placed into four priority groups. Each priority group qualifies for different processing time standards as prescribed in table 3-2. These priority groups are compatible with the transportation priorities prescribed in the Military Standard Transportation and Movement Procedures (MILSTAMP).

1. Force/activity designators.

a. A force/activity is:

(1) A unit, organization, or installation performing a function or mission.

(2) A body of troops, ships, or aircraft, or a combination thereof.

(3) A function, mission, project, or program, including those under military assistance (grant aid and/or sales).

2. Selection and assignment of issue priority designators for requisition and issue transactions.

a. All requests for material normally stocked in a supply system will be assigned an issue priority designator. The issue priority designator normally expresses the relationship between the force/activity designator and the urgency-of-need designator. However, there are certain exceptions and unusual circumstances under which a requisitioning activity is authorized to assign a specific numerical priority designator that represents a uniform need for an item regardless of the force/activity designator assigned. These exceptions are as follows:

(1) A priority designator of 03 will be used by all activities regardless of force/activity designator in requisitioning high value items required for immediate use; i.e., where urgency-of-need designators A or B are indicated.

(2) A priority designator of 03 will be used by all activities, regardless of force/activity designator, for medical or disaster supplies or equipment required immediately for prolonging life in case of critical injury, fatal disease, or natural emergency.

(3) A priority designator of 06 will be used by all activities, regardless of force/activity designator for the replenishment of high value items.

(4) A priority designator of 06 will be used by all activities regardless of force/activity designator, for individual and organizational clothing required to provide a minimum of essential clothing in the event active duty military personnel are without the clothing required.

b. Except for conditions referenced above, the requisitioner will:

(1) Select the applicable urgency-of-need designator for each requisition or order.

(2) Ascertain the appropriate issue priority designator for the force/activity designator assigned the requisitioning activity and the applicable urgency-of-need code, and enter this number on the material requirement document (NAVSTRIP requisition).

c. Supply activities, when requisitioning a specific requirement for a supported unit with a different force/activity designator than the supplying activity, will use the priority designator appropriate to the requiring activity.

3. Every activity is assigned 1 of 5 force/activity designations according to their military importance. See table 3-3. These designators are as follows:

I – COMBAT–The highest order of military importance. This designator is not normally used in peacetime unless approved by the President or the Joint Chiefs of Staff.

II – POSITIONED–United States combat, combat ready, and direct combat support forces deployed outside CONUS in specific theaters or areas designated by the Joint Chiefs of Staff and those CONUS forces being maintained in a state of combat readiness for immediate (within 24 hours) deployment or employment.

III – READY–All other United States combat ready and direct combat support forces outside CONUS not included under designator II.

IV – RESERVE AND SUPPORT–U.S. active and selected reserve forces planned for employment in support of approved joint war plans. This category includes training units and units in training for scheduled deployment.

V – OTHERS–All units not otherwise assigned, including administrative/staff type units.

4. The urgency of need for an aircraft spare part or aeronautical material may be determined in accordance with the following designators (A, B, C, and D):

A – Emergency requirements for primary weapons, equipment, and material for immediate use without which the unit

Table 3-3.—Priority number chart.

Designator	A Unable to perform	B Impairs capability	C Other than routine	D Routine
I Combat	1	4	11	16
II Positioned	2	5	12	17
III Ready	3	6	13	18
IV Reserve and support	7	9	14	19
V Others	8	10	15	20

concerned is unable to perform assigned operational missions (NORS), or such condition of readiness is imminent. (See notes 1 and 2.)

Material required for immediate installation on or repair of primary weapons and equipment, without which the unit concerned is unable to perform assigned operational missions (NORS), or such condition of readiness is imminent. (See notes 1 and 2.)

Items required for immediate end use in direct support of equipment essential to the operation of aircraft and equipment (e.g., ground support, firefighting, etc.), or such condition of readiness is imminent. (See notes 1 and 2.)

B – Item(s) required for immediate end use, the lack of which is impairing the operational unit concerned. The aircraft or organizational unit concerned can operate only temporarily as an effective unit; assigned operational missions can be accomplished, but with decreased effectiveness and efficiency.

Item(s) required for immediate end use to effect repairs to aircraft and aircraft support equipment, without which the operational capability of the aircraft is impaired or effectiveness in accomplishing assigned missions is reduced.

Item(s) required to effect emergency repair or replacement of intermediate maintenance activity equipment essential to providing services for aircraft and aircraft equipment.

C – Items required for immediate end use to repair or replace administrative support equipment and equipment or systems not essential to operational missions of aircraft or organizational units.

Items essential to initial outfitting or to completion of allowance/load lists on a more urgent basis than routine stock replenishment.

Material required to preclude a work stoppage or prevent delay in scheduled maintenance of weapons systems or major equipment.

D – Items required for routine stock replenishment.

Items required for initial outfitting and filling of allowances.

Items required for scheduling maintenance, repair, or manufacture of supply system stocks.

NOTE 1: Requirements of this nature are of such a consequence as to require a report to higher authority of a degradation of the requisitioning units capability.

NOTE 2: An imminent condition of degraded readiness exists when material is required to prevent an Anticipated Not Operationally Ready Supply (ANORS) condition. An ANORS condition will exist when it is known that items of material or equipment, not available in the unit, are required within the following time frames:

a. Five (5) days for nondeployed units.
b. Seven (7) days for deployment units.
c. Fifteen (15) days for combat requirements.

PREEXPENDED BINS

Common repair parts that are considered to be high in usage and low in unit cost are expended from Supply Department stock records and related financial accounts for placement in preexpended bins. The supply officer is primarily responsible for proper management and maintenance of preexpended bins, including display, labeling, and initiating replenishment or turn-in action when required. Recurring issues of consumable items for the repair of equipment are preexpended candidates. Such items are usually general purpose hardware (nuts, bolts, etc.), consumable repair parts (resistors, capacitors, etc.), and bulk material (electrical wire, lubricant, etc.). Items having a unit cost of $10.00 or less may be preexpended. The maximum inventory of any one item at any one outlet must not exceed a 30-day estimated supply. Items having a unit cost exceeding $10.00 may be preexpended with approval of the commanding officer.

Specific items added to or deleted from preexpended bins are determined jointly by the supply officer and the maintenance officer having cognizance over the shop in which such bins are located. Preexpended bins will be established in areas where maintenance is being performed and should be located in these maintenance areas where they are readily accessible to maintenance personnel.

ROTATABLE POOLS

Rotatable pools consist of a range of selected components maintained by a specific maintenance activity, on custody from the supporting supply department. The items generally carried in the pool are those required to sustain operations where immediate availability is essential. To be included in the pool, an item should meet all of the following conditions:

1. Be capable of repair by the local AIMD.
2. Have application relationship to weapons systems supported by the local AIMD's.
3. Have an average removal rate of at least one per month.

An official list of pool items is prepared by the supply officer and provides a ready reference for components carried in pools. Lists are distributed to supply and maintenance units as required and include manufacturer's part number, manufacturer's code, FSN, WUC, nomenclature, and item number in various combinations. Organizations need a list in WUC sequence and another list in part number sequence showing the various part numbers and FSN's used to order an item.

HIGH VALUE ASSET CONTROL MATERIAL

The High Value Asset Control (HIVAC) program is a program of high value item management for the Department of the Navy. The purpose of this program is to achieve inventory economies, without impairing combat readiness, through specialized management of certain high value items. Items subject to the HIVAC system are designated as such by the applicable inventory manager, based on the volume of their annual demand and their unit price.

Although the technician is not directly involved in the program, he is involved at fleet level in that some of these items will be installed in aircraft or held in rotatable pools for which he may be required to assume responsibility. The major responsibility of fleet personnel is supply discipline, since supply discipline in the fleet is an especially critical aspect of the high value program. This is because of the greater difficulty of maintaining accountability under the pressure of operating conditions. Also, prompt action on the part of fleet personnel to expedite handling of high value items is essential to the program. For complete and detailed information concerning the HIVAC system, refer to SecNavInst. 4440.29 (Series) and NavSupInst. 4440.105 (Series).

AIRCRAFT MAINTENANCE MATERIAL READINESS LIST PROGRAM

The Aircraft Maintenance Material Readiness List (AMMRL) Program provides for the data required for effective management of support equipment at all levels of aircraft maintenance. The objective of this program is to document factual data and in-use asset information concerning ground support equipment (GSE) which can be used by management for the following purposes:

1. The determination and establishment of allowance requirements for GSE at intermediate or organizational maintenance activities.
2. Redistribution of in-use assets.
3. To provide a base for budgeting of GSE requirements.
4. To measure material readiness.

This section defines GSE, discusses the background of the AMMRL program, and explains the Application Data for Material Readiness List (ADMRL) and Individual Material Readiness List (IMRL).

GROUND SUPPORT EQUIPMENT (GSE)

GSE is equipment that is required to maintain, service, handle, overhaul, test, or operate a weapon, system, or equipment ashore or afloat. It includes specialized or peculiar equipment (such as test equipment for a specific avionics component) as well as general purpose support equipment. Some examples are as follows: avionics test bench equipment; special handling equipment such as engine and aircraft slings and special tools; and general support equipment, such as tow bars, tow tractors, mobile power units, maintenance stands, power tools, or sewing machines.

Accountable items of GSE are assigned material accountability recoverability code (MARC) "D" or "E." Those accountable items of GSE stocked under "2R" and "8R" cognizance are assigned material control code (MCC) "X."

AMMRL BACKGROUND

The AMMRL program was initially established by BuWeps (now NavAir) in May 1960 for the management of ground support equipment. Prior to that time, each fleet aircraft maintenance activity was required to consult the many and varied types of allowance lists covering support equipment and to determine its own requirements. However, BuAer (Subsequently BuWeps and now NavAir) and ASO were determining overall fleet requirements 2 or 3 years prior to the fleet activities determining their requirements. In almost all cases the BuAer/ASO determinations did not agree with the determinations made by fleet activities. In addition, there was no provision for feedback information to BuAer and ASO of equipment that the fleet activities had on hand. There were no reliable facts on which to determine requirements and to provide budgeting information, and this resulted in inaccurate procurements and distribution of GSE.

These problems resulted in the development of the AMMRL program which provides a means for the determination of immediate and forecasted requirements for each activity.

RESPONSIBILITIES

The proper determination, budgeting, acquisition, and distribution of GSE is the ultimate responsibility of NavAirSysCom. However, the bulk of the day-to-day work concerning the maintenance of records for equipment in use and the location of in-use equipment is placed with the NavAirSysComReps LANT/PAC/Pensacola. They represent NavAirSysCom within geographical areas of responsibility. (NavAirSysComRep Pensacola's responsibility encompasses all of the naval air training activities.) Some of the NavAirSysComReps' responsibilities include the following:

1. Scheduling, preparing, and maintaining IMRL's for all Navy aircraft maintenance activities.
2. Obtaining in-use inventories and maintaining inventory data.
3. Maintaining an ADMRL file.
4. Furnishing consolidated inventory reports to NavAir for activities within their area of responsibility.
5. Participating in ADMRL technical review conferences and AMMRL review boards.

ADMRL

This is a master list of requirements of GSE as applied against intermediate level and organizational level maintenance activities for selected ranges of aircraft, engines, or systems. For example, it contains allowances for all of the avionics test equipment required to support the A-7E aircraft on both the AIMD and squadron level based on the number of aircraft (for the squadron) or the number of systems supported (for AIMD). It contains all GSE (and its application) used in the Navy.

ASO maintains the master updated ADMRL on tape and furnishes it to the NavAirSysComReps when required. ASO enters all technical changes such as changes in quantity, addition of new items, or changes of maintenance levels, as approved by NavAirSysCom.

From this master file (ADMRL), the Individual Material Readiness Lists (IMRL's) are prepared. For example, when a squadron gets a completely new type of aircraft, the NavAirSysComReps can extract the allowances of GSE required for organizational level maintenance for that type and number of aircraft and construct an IMRL which becomes the squadron's allowance for GSE.

INDIVIDUAL MATERIAL READINESS LIST (IMRL)

This is an allowance listing for GSE that is tailored to each organizational or intermediate maintenance activity based on the numbers and types of aircraft, aircraft engines, or aircraft systems supported.

The IMRL is printed in three basic sections which are discussed in the following paragraphs.

Figure 3-2 illustrates the different sections of the IMRL.

Cross Reference Section

This section is used to assist in identifying and locating material in the IMRL. It is broken down into three cross reference parts to aid in this location and identification. The parts are as follows:

FIIN SEQUENCE CROSS REFERENCE.–This part lists all prime items of equipment in FIIN sequence. The FIIN is cross referenced to a sequence number (column 1) which shows the section of the IMRL in which that particular FIIN appears.

NOUN SEQUENCE CROSS REFERENCE.–In this part is listed all prime items of equipment in alphabetical sequence by noun nomenclature. Each item in this part is also cross referenced to a sequence number column 1. An example of this part is shown in figure 3-2 (A).

AVIONICS CROSS REFERENCE.–In this part is listed all of the avionics systems applicable to that particular IMRL. The major avionics systems are listed in alphabetical order and all the test equipment allowed for a particular system is shown, indented three spaces directly underneath the applicable system. An example of this part is shown in figure 3-2 (B).

Single Application Section

This section is composed of items that are applicable to only one specific aircraft model. An example of this section is shown in figure 3-2 (C).

Multiple Application Section

This section contains those items that apply to more than one type of aircraft. Figure 3-2 (D) illustrates this section.

Definition of Columns

The following subparagraphs explain the different headings and columnar format of the IMRL pages which are illustrated in figure 3-2.

IDENTIFICATION DATA.–This heading consists of two columns. In column (1) is listed the cross reference sequence numbers. Shown in column (2) are the FSN, part number, and in the case of the single and multiple application sections, alternate items, which are indented three spaces immediately below the prime number.

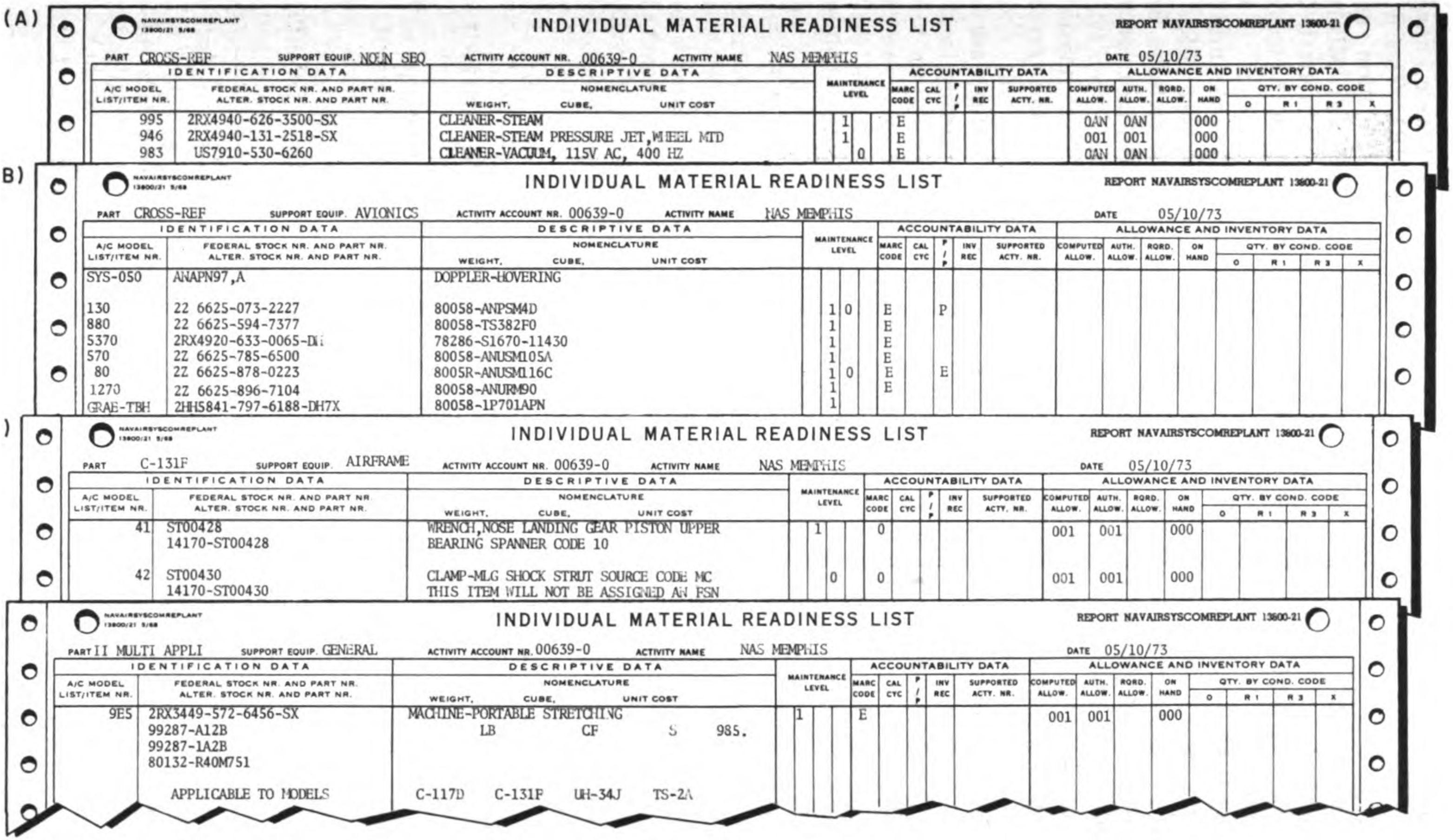
DESCRIPTIVE DATA.–This heading consists only of column (3). A complete description of the IMRL item is shown; and in the case of the multiple application section, the multiple aircraft types to which the particular item applies are shown. Also provided is such information as weight, cube, and unit cost.

MAINTENANCE LEVEL.-This heading consists of columns (4) through (7). Column (4) is always left blank. Column (5) contains the letter "I" if the item applies to intermediate level maintenance. Column (6) contains the letter "O" if the item applies to organizational level maintenance. Column (7) contains the letter "T" if the item applies to transit support.

ACCOUNTABILITY DATA.–This heading includes columns (8) through (12). Column (8) contains the MARC code of the item. Column (9) contains a calibration cycle code, if applicable. Column (10) contains a pre-positioning code, if applicable. A pre-positioning code pertains to items applicable to organizational maintenance level items (code "O," column (6)) that must be checked out from the AIMD. The AIMD must account for and report these items. The following subparagraphs explain the three pre-positioning codes:

1. Code "P." This code indicates that the item is available on a subcustody basis from the supporting AIMD.
2. Code "E." This code indicates the item is available from the AIMD on an "as required" basis.
3. Code "L." This code identifies items which are issued to squadrons by the parent activity AIMD on subcustody but which may be retained by the squadron while they deploy.

Column (11) is left blank. In column (12), the activity's identification number is given.



(A)

NAVAIRSYSCOMREPLANT 13800/21 5/68

INDIVIDUAL MATERIAL READINESS LIST

REPORT NAVAIRSYSCOMREPLANT 13600-21

PART CROSS-REF SUPPORT EQUIP. NOUN SEQ ACTIVITY ACCOUNT NR. 00639-0 ACTIVITY NAME NAS MEMPHIS DATE 05/10/73

IDENTIFICATION DATA		DESCRIPTIVE DATA		ACCOUNTABILITY DATA					ALLOWANCE AND INVENTORY DATA							
A/C MODEL LIST/ITEM NR.	FEDERAL STOCK NR. AND PART NR. ALTER. STOCK NR. AND PART NR.	NOMENCLATURE WEIGHT, CUBE, UNIT COST	MAINTENANCE LEVEL	MARC CODE	CAL CYC	P/P	INV REC	SUPPORTED ACTY. NR.	COMPUTED ALLOW.	AUTH. ALLOW.	RQRD. ALLOW.	ON HAND	QTY. BY COND. CODE O	R1	R3	X
995	2RX4940-626-3500-SX	CLEANER-STEAM	1	E					0AN	0AN		000				
946	2RX4940-131-2518-SX	CLEANER-STEAM PRESSURE JET,WHEEL MTD	1	E					001	001		000				
983	US7910-530-6260	CLEANER-VACUUM, 115V AC, 400 HZ	0	E					0AN	0AN		000				

(B)

NAVAIRSYSCOMREPLANT 13800/21 5/68

INDIVIDUAL MATERIAL READINESS LIST

REPORT NAVAIRSYSCOMREPLANT 13600-21

PART CROSS-REF SUPPORT EQUIP. AVIONICS ACTIVITY ACCOUNT NR. 00639-0 ACTIVITY NAME NAS MEMPHIS DATE 05/10/73

IDENTIFICATION DATA		DESCRIPTIVE DATA		ACCOUNTABILITY DATA					ALLOWANCE AND INVENTORY DATA							
A/C MODEL LIST/ITEM NR.	FEDERAL STOCK NR. AND PART NR. ALTER. STOCK NR. AND PART NR.	NOMENCLATURE WEIGHT, CUBE, UNIT COST	MAINTENANCE LEVEL	MARC CODE	CAL CYC	P/P	INV REC	SUPPORTED ACTY. NR.	COMPUTED ALLOW.	AUTH. ALLOW.	RQRD. ALLOW.	ON HAND	QTY. BY COND. CODE O	R1	R3	X
SYS-050	ANAPN97,A	DOPPLER-HOVERING														
130	22 6625-073-2227	80058-ANPSM4D	1 0	E		P										
880	22 6625-594-7377	80058-TS382F0	1	E												
5370	2RX4920-633-0065-DH	78286-S1670-11430	1	E												
570	2Z 6625-785-6500	80058-ANUSM105A	1	E												
80	2Z 6625-878-0223	8005R-ANUSM116C	1 0	E		E										
1270	2Z 6625-896-7104	80058-ANURM90	1	E												
GRAE-TBH	2HH5841-797-6188-DH7X	80058-1P701APN	1													

(C)

NAVAIRSYSCOMREPLANT 13800/21 5/68

INDIVIDUAL MATERIAL READINESS LIST

REPORT NAVAIRSYSCOMREPLANT 13600-21

PART C-131F SUPPORT EQUIP. AIRFRAME ACTIVITY ACCOUNT NR. 00639-0 ACTIVITY NAME NAS MEMPHIS DATE 05/10/73

IDENTIFICATION DATA		DESCRIPTIVE DATA		ACCOUNTABILITY DATA					ALLOWANCE AND INVENTORY DATA							
A/C MODEL LIST/ITEM NR.	FEDERAL STOCK NR. AND PART NR. ALTER. STOCK NR. AND PART NR.	NOMENCLATURE WEIGHT, CUBE, UNIT COST	MAINTENANCE LEVEL	MARC CODE	CAL CYC	P/P	INV REC	SUPPORTED ACTY. NR.	COMPUTED ALLOW.	AUTH. ALLOW.	RQRD. ALLOW.	ON HAND	QTY. BY COND. CODE O	R1	R3	X
41	ST00428 14170-ST00428	WRENCH,NOSE LANDING GEAR PISTON UPPER BEARING SPANNER CODE 10	1	0					001	001		000				
42	ST00430 14170-ST00430	CLAMP-MLG SHOCK STRUT SOURCE CODE MC THIS ITEM WILL NOT BE ASSIGNED AN FSN	0	0					001	001		000				

(D)

NAVAIRSYSCOMREPLANT 13800/21 5/68

INDIVIDUAL MATERIAL READINESS LIST

REPORT NAVAIRSYSCOMREPLANT 13600-21

PART II MULTI APPLI SUPPORT EQUIP. GENERAL ACTIVITY ACCOUNT NR. 00639-0 ACTIVITY NAME NAS MEMPHIS DATE 05/10/73

IDENTIFICATION DATA		DESCRIPTIVE DATA		ACCOUNTABILITY DATA					ALLOWANCE AND INVENTORY DATA							
A/C MODEL LIST/ITEM NR.	FEDERAL STOCK NR. AND PART NR. ALTER. STOCK NR. AND PART NR.	NOMENCLATURE WEIGHT, CUBE, UNIT COST	MAINTENANCE LEVEL	MARC CODE	CAL CYC	P/P	INV REC	SUPPORTED ACTY. NR.	COMPUTED ALLOW.	AUTH. ALLOW.	RQRD. ALLOW.	ON HAND	QTY. BY COND. CODE O	R1	R3	X
9E5	2RX3449-572-6456-SX 99287-A12B 99287-1A2B 80132-R40M751	MACHINE-PORTABLE STRETCHING LB CF S 985.	1	E					001	001		000				
	APPLICABLE TO MODELS	C-117D C-131F UH-34J TS-2A														

AK.257

Figure 3-2.—The IMRL. (A) The noun sequence cross reference; (B) the avionics cross reference; (C) Part I, the single application section; (D) Part II, the multiple section.

ALLOWANCE AND INVENTORY DATA.– This heading includes columns (13) through (20). The following subparagraphs explain these columns:

1. Column (13). In this column is shown the allowance as extracted from the ADMRL.
2. Column (14), authorized allowance This is the allowance as approved by the applicable NavAirSysComRep and Air Type Commander.
3. Column (15), required allowance. This is the quantity deemed necessary by the applicable activity. It is not a firm allowance and if it does not agree with column (14), there should be a request for a change in allowance pending.
4. Column (16), on hand. In this column is shown the total on hand quantity for all condition codes.
5. Columns (17) through (20). These columns contain the quantity of items on hand by each condition code.

Maintenance of the IMRL

Although the following information is concerned with the AK rating, it is important for the AQ to realize that he must provide the inputs to the AK before any action will be taken and therefore he must have a knowledge of the maintenance of the IMRL. This is a large and extremely important function and becomes quite complicated at a large AIMD that supports several different types of aircraft. The maintenance of the IMRL includes the following:

1. Establishment of procedures for control and custody of accountable IMRL equipment.
2. Reporting all transactions involving the permanent transfer, receipt, or condition change of IMRL items.
3. Conducting an annual physical inventory and submission of the annual report of inventory of IMRL equipment.
4. Insuring that all shortages are ordered.
5. Consolidating, preparing, and submitting requests for IMRL changes.

CHAPTER 4

MAINTENANCE PROCEDURES AND SPECIAL PROBLEMS

Avionics maintenance in the Navy is big business and a big problem. It involves thousands of different materials, components, equipments, and systems. More important, it involves trained manpower.

How well any piece of equipment performs depends upon the ability of the men who operate and maintain it. If these men cannot maintain the equipment at the desired level of operation, its usefulness descends toward and often approaches zero. Malfunctions in avionics equipment are hazardous. They are not only hazardous to flight personnel, but can also result in the damage or destruction of valuable aircraft.

Maintenance should be preventive in nature, where potential failures are detected and corrected before they have an opportunity to develop into complete equipment breakdown. Timely replacement of parts exhibiting evidence of failure will help prevent breakdown and will lengthen the useful life of the equipment or system.

EVALUATING DISCREPANCIES

Since it is impossible through preventive maintenance to prevent all equipment failures or malfunctions there is a need for corrective maintenance. This type of maintenance requires the application of intelligent evaluation and troubleshooting procedures. In order that maximum efficiency be realized, it is of utmost importance that evaluation of discrepancies be carried out in logical sequence. When the malfunction occurs during flight, this should begin with a debriefing of the flight crew.

DEBRIEFING FLIGHT CREWS

When operating complex weapons systems an operator-maintenance debriefing procedure is necessary. A detailed debriefing of the flight crews' experiences and a complete analysis of the reported discrepancies are desired. Many man-hours can be saved by knowing what the trouble is and what is required to correct it before scheduling any maintenance action.

The physical location for the debriefing will vary and is usually designated by maintenance control. For squadrons operating ashore, debriefing can be accomplished in maintenance control during or immediately after the time the flight crew completes the "yellow sheet." Sometimes the location of the fire control shop will be such that it can be used to better advantage. Onboard ship the readyroom is normally used for this purpose since it is the place from which squadron operations are directed.

In order to obtain the most from the debriefing, the supervisor should insure that it is conducted in an efficient manner by the most experienced and best qualified technicians.

CORRECTING DISCREPANCIES

Isolating a trouble to a particular unit (assembly) or subassembly is only a small part of the entire solution of the problem.

The main and pressing objective of discrepancy correction is that of getting the aircraft back in commission the quickest way possible. The period of time required to accomplish this objective will be determined by several factors.

The seriousness of the discrepancy, availability of spare parts, and the workload carried at the time are all factors affecting aircraft downtime. One of the most important factors is the decision made by the supervisor and his assigned crew leaders as to the exact method used to solve the problem. One of the following questions should hold the clue:

1. Can the trouble be adjusted out by some portion of alinement?
2. Can the needed repair be accomplished on the aircraft?
3. Is it necessary (or better) to remove and repair a unit or part and return it to the aircraft?
4. Is replacement of a unit or part required?

ADJUSTMENTS

Many times an adjustment or partial alinement will correct the discrepancy, but for the day-to-day line maintenance problems avoid becoming involved in long drawn-out alinement procedures if possible. This is because of the tendency of maintenance crews to hurry when attempting long alinement while being pressed for time. Excessive speed usually results in poor alinement or sometimes in misalinement and no progress will be accomplished.

This is not meant to imply that necessary alinements can be omitted. There will be times when a complete system alinement will be necessary to return the equipment to efficient operation. This will be a decision for the crew leader or supervisor.

In the event that adjustment or alinement is required, the currently approved alinement procedures, as described in the appropriate equipment manual, must be used. Unless the adjustments are relatively few and simple, reliance on memory for an alinement is not a good practice since it will probably result in a waste of time and poor alinement. A misalinement will likely be the end result and the entire system will have to be alined a second time.

Some adjustments are critical and difficult to make. Others are simple and are provided with a large range in which to work, but the ability to make an adjustment or perform an alinement properly improves with experience. Each technician should be urged to make a concentrated effort in this area, because it will mean the difference between average or marginal operation and peak performance.

MAINTENANCE RESPONSIBILITIES

Squadrons report the degree of operational readiness they achieve. The material management practices of the squadron and those of the supporting maintenance and supply activities are responsible, to a large degree, for the squadron's not operationally-ready time. Unnecessary and significant increases in downtime may be caused by:

1. Initiation of an improper material request document by the squadron.
2. Improper troubleshooting practices, which replace nondefective material.
3. Delay of turn-in of defective material by squadrons, thereby delaying its return to RFI status.
4. Intermediate and depot maintenance level activities not returning a NORS item to an RFI condition in an expeditious manner.
5. Improper management of rotatable pools, including proper depth, range, and expeditious repair actions.
6. Lack of adequate material planning and technical research by maintenance and supply personnel.
7. Lack of communications/coordination between maintenance and supply personnel.
8. Improper or lack of full utilization of existing resources for repair of aeronautical material.
9. Failure to initiate requests for resources to improve maintenance capability above that presently authorized.
10. Improper application of established maintenance and supply practices, disciplines, or policy.
11. Preinspection requisition of high time replacement components not accomplished.

Any one of the above conditions, among others, will cause a substantial reduction in operational readiness.

Maintenance functions are those assigned to an activity actually performing maintenance work on the aircraft or associated equipment and responsible for troubleshooting, the repair or replacement of the failed item, testing and certification that the aircraft/equipment is ready, and initiating proper requests for material. Maintenance functions include the responsibility to provide supply with:

1. A valid part number and manufacturer's code from an illustrated parts breakdown or a technical reference.
2. A priority indicator and project code for the material request, in accordance with current directives.
3. The defective repairable component, immediately upon removal from the aircraft and concurrently with placing the demand on supply The only exception to this time frame is when the defective component is required to remain in place (i.e., safety of flight, weight and balance, transfer of adapters/attachments, etc.) until receipt of the replacement component. Material turn-in/pick up time of these defective components must be accomplished within 24 hours after receipt of the replacement component. When advised that replacements for defective components causing a NORS/NFE condition are not available on board, the defective component is removed as operations permit and turned in for expeditious repair by the AIMD. Other defective material, i.e., source code A, M, and X series, are forwarded only when required for customer service at the depot level.
4. Technical assistance in determining interchangeability, alternate procurements, substitution, and possible local purchase. Maintenance and supply activities must establish a close relationship in order to assure optimum results and improved readiness. The technical background for making these determinations is usually available only in the maintenance cadre.

DISCREPANCY TRENDS

By careful and continuous reference to the daily discrepancy reports, Work Center Registers, etc., a definite trend in discrepancies may be detected. Detection in itself is not difficult. The big problem is reducing these indications to basic causes or reasons for such trends. Sometimes they can be traced to improper maintenance procedures such as misalinement caused by maintenance personnel not adhering to the specifically outlined procedures. Perhaps the problem will be revealed by an investigation of the test equipment being used. Such an investigation may disclose improper operation of test equipment or that the error tolerances have been exceeded. At other times an equipment deficiency, especially in newer types of equipment, can be "pinned down" as the reason. If there should be an equipment deficiency, the supervisor should make sure that an Unsatisfactory Material/Condition Report (UR) is completed and forwarded so that corrective action may be taken after further investigation by the Naval Air Systems Command. No matter what the cause, an analysis of the problem is required when a trend in discrepancies is noted.

ANALYZING DEFICIENCIES

In order to properly analyze any problem the technician must have a thorough understanding of the operation of the equipment being maintained and of the test equipments necessary to maintain it. Armed with this information and with a sincere and conscientious approach, almost any maintenance problem can be deliberately and systematically resolved in reasonable time. Most of the difficult and many of the seemingly impossible problems have been solved by careful and painstaking testing and recording of indications obtained through voltage and resistance checks, waveform comparisons, and the application of basic theories. The more difficult the problem the more exacting the applied procedures and tests must be.

The major contribution to analyzing a problem is a clear and orderly thought process. The technician must provide this ingredient since test equipment, charts, and tables will only contribute the necessary material to be used in these thoughts.

While the supervisor is involved in analyzing these deficiencies, he may discover a better method of alinement or find a potential trouble spot in the equipment for which he may help find a solution by making known a suggestion to remedy the situation. By so doing he will be aiding in the entire program of improving productivity by saving man-hours and material. This process is known as Value Analysis in Maintenance Operations (VAMO).

Value Analysis in Maintenance Operations

VAMO can be defined as a systematic and continuing evaluation of those factors affecting the efficient maintenance of a component, equipment, or system. It encompasses functional as well as engineering design standardization, and reliability as well as ease and frequency of maintenance operations. The maintenance supervisor accepts his responsibility to keep the equipment in readiness and conscientiously attempts to "keep them flying." He will not knowingly compromise the functioning of equipment under his jurisdiction even though occasionally he must ground aircraft because of insufficient time to complete a job. When an aircraft is grounded it affects the fulfillment of the Navy's mission. Value maintenance, if objectively and actively pursued, can result in increased maintenance efficiency by saving manhours of shop time and can thereby result in fewer grounded aircraft.

Through value analysis, and through human and design engineering, efforts are continually being made to build maintainability and reliability into all new components, equipments, and systems. This is fine, but it is not enough—the one missing ingredient is the knowledge of how a specific component, equipment, or system performs under actual operating conditions—and what to do to improve this performance. This is where the maintenance supervisor has the "front seat." He is in a position to get first-hand information based on operating experience. He is able to observe the degree of maintainability and reliability designed into the equipment. If he is satisfied to accumulate such data only for his own or his immediate associates' use and does not bother to pass it along, he is missing a great opportunity to share in the building of the Navy's effectiveness.

Remember, you are a Navy maintenance supervisor, and you earned your rating by having the ability and intelligence to do the job. Maintenance in many respects is just as important in the overall picture as the original design. Any equipment that requires repeated maintenance as well as frequent downtime for routine inspection is not serving the Navy to best advantage. Such equipment presents a logistic problem which costs money. You, as a maintenance supervisor, can often remedy such situations simply by sharing your time saving ideas. Remember, constructive criticism and suggestions are always welcome. The few minutes your method saves may seem insignificant; but if others are also able to save those minutes by following your shortcuts, the Navy will be able to measure its savings in hours or days.

Consider evaluating your equipment for places where improvements can be made. There are many potential trouble-spots that rate particular attention. A few examples of the kinds of questions maintenance men should ask and items they should keep in mind are listed below for future reference. This is not an all-inclusive list—it never could be, because new equipment and new equipment locations will always present new problems. VAMO is a continuing challenge to your ingenuity as a maintenance supervisor.

1. Are controls and adjustments located so that they can be seen readily and reached without difficulty? You should not be expected to disassemble or remove any part of an equipment for access during maintenance.
2. When replacing a component. you should not have to remove other components.
3. Connecting cables should be long enough to permit withdrawing the equipment for access to adjustments without breaking the electrical connections. In modulized equipment a test (extension) cable should be provided, thus permitting the unit to be serviced without demounting the entire assembly.
4. Be especially careful to look for unkeyed connectors having a symmetrical pin arrangement that could be misconnected inadvertently. Also look for places where the wrong connector could be inserted because of its similarity in size, etc., to the correct one.
5. Look for operations that are hazardous (either from an electrical shock or physical standpoint). It takes a lot longer to make an adjustment in a cramped physical position than when the control is located at a convenient level.
6. Quick, easily identifiable component nomenclature is always a must. Minutes of search time can be saved.

In summary, remember that any unusually difficult operation should be analyzed for a simpler solution. Once you have solved the problem, share your solution with others.

Although the Navy does not have a specific, formalized program of VAMO, it utilizes value analysis principles daily. The Material Reliability Program is an excellent example of an important phase of value maintenance. This program, in part, utilizes the Unsatisfactory Material/Condition Report (UR). Operating activities are responsible for prompt submission of UR's. The maintenance supervisor should make every effort to determine the precise causes of component failures or malfunctions, particularly those involving aircraft accidents. If this cannot be done locally, priority disassembly and inspection reports or laboratory analysis reports, as appropriate, should be requested.

Every time you make out a UR, you are setting in motion a far-reaching program for the evaluation of faults, malfunctions or failures of materials. These reports must be analyzed; statistics must be collected and correlated; and the results must be evaluated and fed back to personnel who are responsible for seeing that any needed corrective action is taken. The results of the UR programs are commendable. Changes resulting from these reports release thousands of maintenance man-hours for other tasks which help to keep our aircraft in the air and may even save lives by eliminating dangerous conditions.

The maintenance supervisor's contribution to the Value Maintenance operation should not be limited to submitting UR's. When he discovers a design deficiency, publications error, or improper supply parts or FSN's he should take action by one of two methods. First, he can request his division officer to initiate an official letter, via the chain of command, to the Naval Air Systems Command. The other method is to ask for the assistance of a NAESU field engineer. This engineer will analyze the problem and prepare and forward a technical report to NAESU Headquarters. The report will be reviewed by NAESU and forwarded with recommendations for corrective action. This method will sometimes bring corrective action much sooner than the first.

DEVELOPMENT OF INSPECTION PROCEDURES

In developing good inspection procedures, it is necessary to first establish an acceptable quality level of work, keeping in mind that safety must always come first. Next a continuing procedure for analyzing discrepancy trends must be created; records must be kept; and followup action must be provided to stimulate improved workmanship. The crew's thinking must be influenced so as to incorporate principles of quality control in each step of the job. Technicians should be encouraged to help each other by double-checking each other's work as they go along. Any job is properly accomplished by first delegating it to those who can and should be doing it; therefore, the best qualified technicians must be assigned to perform the inspection. Insure that these men have all the specifications and records needed to perform the inspections. Every man in the crew must understand that an inspection is not to fix blame or to comply with a requirement, but to save aircraft and lives and to provide the best operating equipment possible.

The morale and physical condition of the crew are equally important as their technical ability. If a man works beyond his physical capability, he does not take time to do each job with painstaking care. Morale, which is a product of leadership, plays a vastly important role in the maintenance program since it can so adversely affect the flight support effort. This in turn will deny a good safety environment regardless of the fact that the maintenance personnel are well trained. The supervisor must set a good example because people try to imitate or take for their own those qualities they admire in those they identify as their leaders. If the leaders are respected and admired as good, aggressive professionals who create by their interest and actions a good attitude toward flying and safety, then the maintenance program will be good.

With good leadership we are assured of high morale. This combined with good maintenance training and good quality assurance will insure good maintenance and flight support.

SPECIAL MAINTENANCE PROBLEMS

The effect of environmental conditions upon the operation of electronic and electrical equipment has greatly increased the maintenance problems of the technician. These conditions may be grouped under the major headings of altitude, temperature, and humidity. At the extremes of these conditions special maintenance and operating procedures are required. Equipments required to function at these extremes frequently fail due to the effect of decreased air density, radical temperature changes and moisture.

Other special maintenance problems are introduced by the effects of electromagnetic interference. Among the types of electromagnetic interference discussed in the following paragraphs are manmade sources, natural sources, and the inherent sources. Also discussed are methods used to suppress electromagnetic interference.

ENVIRONMENTAL EFFECTS

The continually increasing complexity of electronic equipments and the subjection of these equipments to more and more rigorous environmental conditions are among the chief causes of equipment failure. Because of these reasons, the technician of today must be able to anticipate and evaluate the effects that environmental conditions may have on the equipments for which they are responsible.

The environmental factors that must be considered include humidity, fungi, temperature, pressure, and atmospheric conditions.

Humidity

High humidity—the arch-enemy of electronic equipment—is one of the principal causes of electronic component and equipment failure. Technicians should have full knowledge of the effects of humidity on the equipments for which they are responsible. High humidity lowers arc-over levels, causes metals to corrode, and produces physical distortion and rapid deterioration and disintegration on many organic compounds. To make matters worse, high humidity is rarely found without condensation and fungi, with their resultant damaging effects.

Moisture control often involves procedures that may prove injurious to components, or which may be the direct antithesis of solutions to other environment-related problems. This is often the case in tropical areas having both high moisture and high temperature. In such a climate, ventilation of the equipment is required for heat dissipation, but exposure to the atmosphere permits the damaging effects of condensation.

Where electronic equipment is to be used under conditions of extremely high humidity, drain channels and drip holes are sometimes incorporated in the chassis of certain equipments. These openings serve to reduce the overall spread of condensation and reduce electrolytic action. Inspections should include a check of these drains to insure that they are functioning properly.

Woven fabrics and plastic sleeving on delicate or critical components often present a problem of moisture entrapment, with consequent deterioration and failure of the components. Moreover, certain insulations and dielectrics may serve as nutrients for various fungi. Both conditions intensify the need for moisture protection for electronic components.

Under tropical conditions it is sometimes necessary to protect critical component parts from the harmful effects of moisture and temperature variations. Probably the most effective means of doing this is to seal component parts individually. However, sealing equipment or assemblies of component parts does not completely eliminate the problem because such a seal must, at times, be broken for maintenance or repair. In many cases the technician will not have the means or the inclination to keep the component parts free of moisture to the extent required, especially if the equipment must be stored or remain inoperative while replacement parts are on order.

Fungus

Fungus is a form of plant life which feeds on materials of vegetable and animal origin including paper, cotton, such things as dead insects, other fungi, etc. These may be spread by wind, dust, dirt, and insects such as ants, flies, and mites. Growth may take place on materials other than those of organic origin if a spot of dust or other nutrient substance is present.

Fungus growth causes decay, accelerates the deterioration of insulating materials, and short circuits items such as relays, jacks, and keys. The inclusion of a fungicidal compound in the manufacture of the equipment retards the growth of these fungi.

Most new equipment is given a climatic deterioration prevention treatment which provides a reasonable degree of protection against fungus growth, moisture, corrosion, salt spray, insects cold, desert heat and so forth. The treatment involves the use of a lacquer or varnish coating material applied with a spray gun or brush.

The effects of moisture and fungi on different parts and/or material are shown in table 4-1.

Temperature Extremes

The damaging effects of extremely high and low temperatures on electronic equipments, and the ways in which these effects may be lessened or moderated, are becoming well known. Extensive research is being conducted to develop component parts that are better able to withstand operation under extreme temperatures.

The technician must know the effects of temperature changes on the physical dimensions of the electronic parameters of components such as capacitors and slug-tuned inductors. He must also be aware of the mechanical effects of extreme temperatures. Extremely low temperatures cause brittleness in metal and loss of flexibility in rubber, insulation, and similar materials. Extremely high temperatures may cause terminal boards, seals, insulation, and solders to deteriorate and become deformed. Rapid changes of temperature can be especially damaging to electronic component parts.

Pressure Effects

Airborne fire control equipment used at high altitudes is usually pressured for the following reasons:

1. To prevent high-voltage arcing and resultant wear on brushes and relay contacts
2. To prevent RF voltage breakdown in waveguides.
3. To eliminate the problems of condensation and corrosion in the equipment which result from "breathing."

Adequate pressurization of individual components (to preclude failure from thermal and barometric shock) adds considerably to the weight/size ratio of the equipment. The use of enclosing chambers that will both pressurize and cool increase equipment complexity and results in less reliability. Moreover, overall pressurization sealing complicates maintenance. If one component in a chamber fails, the entire unit must be opened, exposing the other components to the effects of atmospheric conditions. A pressurized equipment that is opened for maintenance is not always resealed immediately; therefore, its component parts must be able to resist ground environmental conditions.

Atmospheric Conditions

Atmospheric conditions play a very important part in radar performance. Some of the more common factors are:

1. Duct formation
2. Temperature inversion and atmospheric refraction
3. Rain echoes and scattering
4. Atmospheric absorption

DUCT FORMATION.–Duct formation occurs when there is a sharp discontinuity in the atmospheric conditions close to the ground. The discontinuity reflects a transmitted signal in about the same manner as a metallic surface, in that it directs the wave back to earth where reflection occurs again. Therefore the space between the earth and the discontinuity in effect acts as a waveguide and, as a result, an abnormally long radar range may be observed.

ATMOSPHERIC REFRACTION.–Atmospheric refraction is a phenomenon by which radar waves are bent in the earth's atmosphere. Under normal conditions the atmosphere is more dense at the surface of the earth and less dense as the altitude increases. As a result electromagnetic energy travels more slowly at lower altitudes and is effectively bent downward. The radar horizon is therefore extended about 15 percent beyond the calculated horizon under normal conditions. This phenomenon may be further augmented by a condition known as temperature inversion, which is caused by a warm air mass surmounting a colder air mass. The increased temperature at higher alti-

Table 4-1.—Effects of moisture and fungi.

Parts or material	Effects of moisture and fungi
Fibre: Washers, supports, etc.	Moisture causes swelling which causes the supports to misaline, resulting in binding of supported parts destroyed by fungi. Cold causes washers to become brittle.
Fibre: Terminal strips and insulators	Electrical leakage paths are formed, causing flashovers and cross talk. Insulating properties are lost, destroyed by fungi.
Laminated plastics: Terminal strips and boards, switchboard panels, connectors, etc., tube sockets and coil forms	Insulating properties are lost. Leakage paths cause flash-overs. Delamination occurs and fungi grows on surfaces and around edges. Expansion and contraction under extreme temperature changes.
Moulded plastics: Terminal strips and boards, switchboard panels, connectors, etc., tube sockets and coil forms	Machined, sawed, or ground edges or surfaces are supporters of fungi, causing shorts and flash-overs. Fungus growth reduces resistance between parts mounted on plastic to such an extent that the item is useless.
Cotton, linen, paper, and cellulose derivatives: Insulation, coverings, webbing, belting, laminations, dielectrics, etc.	Insulating and dielectric properties lost or impaired causing arcing and flash-overs. Completely rotted and thus destroyed by fungi.
Wood: Cases, houses, and housings, plastic fillers, masts, etc.	Dry rot, swelling, delamination, caused by moisture and fungi.
Leather: Straps, cases, gaskets, etc.	Fungus destroys tanning and protective materials causing rotting due to moisture, bacteria, and fungi.
Glass: Lenses, windows, etc.	Fungus grows on organic dust, insect tracks, insects feces, dead insects, etc. Dead mites and fungi growth on glass obscures visibility and corrodes nearby metal parts.
Metals	High temperature and moisture vapor cause rapid corrosion. Fungus and bacterial growth produce acids and other products which spread corrosion, etching of surfaces, and oxidation. This interferes with the operation of moving parts, screws, etc., and causes dust between terminals, capacitors, plates of air condensers, etc., which causes noise, loss in sensitivity, and arc-overs.
Metals: Two or more	Different metals which have different potentials when moisture is present, cause electrolysis and one of the metals is plated onto the other, causing formation of salts and deep etching of surfaces. This happens at riveted or bolted joints, bearings, slides, and screw threads.

Table 4-1.—Effects of moisture and fungi—Continued.

Parts or material	Effects of moisture and fungi
Wax: For impregnation	Fungus inhibiting waxes which are not clean support fungi, causing destruction of insulating and protective qualities and permitting entrance of moisture which destroys parts and unbalances electrical circuits.
Soldered joints	Excessive soldering flux on terminal boards hold moisture which speeds up corrosion and growth of fungi. Soldering iron should not come in contact with wire insulation.

tudes further decreases normal atmospheric density, as compared to the surface density, and the radar horizon is greatly extended. Temperature inversion is common where warm air masses from land move over the cool air directly over a large body of water. The opposite condition can also prevail if the gradation of density is reversed, in that a colder air mass surmounts a warm air mass. Refraction will then cause the radar wave to bend upward and thus greatly reduce the radar horizon.

RAIN ECHOES AND SCATTERING.—Moisture in the atmosphere may cause microwave signals to be either scattered or reflected, depending upon the size of the droplets. If the droplets are rather large, as in a heavy rain cloud, reflection occurs and causes an echo. This effect is very noticeable at the higher microwave frequencies. Smaller droplets may cause scattering rather than reflection, causing the range to be greatly reduced.

ATMOSPHERIC ABSORPTION.—Atmospheric gases have the property to absorb certain microwave frequencies. Each gas has its own absorption spectrum and, of the gases studied thus far, each is unique in regard to the absorption of frequencies. For example, water vapor strongly absorbs electromagnetic radiation at frequencies above 10,000 MHz, showing a peak at about 23,000 MHz. Oxygen absorbs RF energy very strongly at about 60,000 MHz, and ammonia gas at about 24,000 MHz. The fact that absorption characteristics of various gases differ markedly has made it possible to analyze gases by means of their absorption spectra. The absorption effect is very undesirable in radar operations because it results in reduced range at the frequencies of maximum absorption. This effect is not pronounced in the X band and at lower frequencies, but it does make the upper part of the K band very unreliable in respect to atmospheric absorption.

CORROSION CONTROL

Corrosion in naval aircraft is a problem requiring the continued attention of all maintenance personnel. The environment in which naval aircraft operate promotes the development of corrosion and requires that specific and continuous measures be applied for its prevention and control.

The high stress loads imposed on modern aircraft and the use of newer lightweight materials in their construction make it even more important that the structural soundness of the weapon system be maintained throughout its service life. Without anticorrosion maintenance, the aircraft would soon deteriorate and become unsafe for flight.

In the past, a lack of emphasis or a complete absence of proper corrosion preventive maintenance resulted in aircraft requiring extended rework at overhaul activities. This situation had serious effects on the Navy's goal of maximum utilization of all available weapon systems and has resulted in the strict requirement for an active corrosion control program for each activity involved in maintaining naval aircraft.

The ability to control corrosion is dependent on an active and continuous program. In most cases the activity will have a fully implemented corrosion control program in existence, but without proper direction and motivation provided by the immediate supervisor, the program can easily become stagnant. Information on the types and nature of corrosion and general maintenance practices is provided in the Rate Training Manual, AQ 3 & 2, NavPers 10387-A.

ELEMENTS OF AN ACTIVE PROGRAM

A corrosion control program that strives to be continuously dynamic must have coordination and motivation. Maintenance/production control is charged with the responsibility of controlling and directing all maintenance efforts within an activity, however, this responsibility is met through the use of subordinate supervisors. In pursuing a complete program of corrosion control, numerous elements must be considered; and while they are generally the concern of maintenance control, it is the unit's corrosion program supervisor that provides the necessary coordination and direction. The supervisor should be knowledgeable of the information provided in the following publications:

1. Aircraft Cleaning and Corrosion Control for Organizational and Intermediate Maintenance Levels, NavAir 01-1A-509.
2. Preservation of Naval Aircraft, NavAir 15-01-500.
3. Appropriate volume of the applicable Maintenance Instructions Manual with specific corrosion control instructions for the weapon system being supported.

While much has been done to improve the corrosion resistance of aircraft in the areas of improved materials, surface treatment, insulation, and protective finishes, corrosion continues to be a very real problem. A corrosion program designed to provide a reasonable solution must include the following elements:

1. Thorough cleaning, preservation, and lubrication at prescribed intervals.
2. Inspection for corrosion damage and protective finish integrity on a scheduled basis.
3. Prompt treatment after detection.
4. Accurate recordkeeping and reporting of material/design deficiency.
5. Adequately trained personnel in areas of detection, treatment, and prevention.
6. Adequate materials, equipment, and technical publications.
7. Proper emphasis to the concept of all hands responsibility for corrosion control.

Training of personnel in proper methods is especially important. Occasionally, maintenance personnel not equipped to treat corroded areas cause more damage and actually aggravate the existing situation rather than control it. The unit's training syllabus should provide thorough training, and corrosion team members should receive the benefit of the special courses offered by the Naval Aviation Maintenance Training Groups and some of the Naval Air Rework Facilities. Team members should be assigned on a permanent basis with normal rotation to other billets within their rating to insure that the repetition of corrosion control tasks does not lead to program stagnation.

EVALUATING THE EFFECTIVENESS OF A CORROSION CONTROL PROGRAM

The effectiveness of the corrosion control program is best reflected by the condition of the weapon system during periodic inspections and can be evaluated by proper recordkeeping and reporting of treatment required on each aircraft and its components. Fullest advantage must be taken of prescribed inspections to detect incipient corrosion or deterioration, to take immediate action to prevent further deterioration, and to correct existing discrepancies.

Documentation of Treatment

All manhours expended towards the corrosion control effort must be documented on the required maintenance data collection forms. Occasionally, activities tend to overuse the Support Action Form (SAF) for this purpose. While the SAF is used to account for washing, rinsing with water, touchup painting, and all other actions taken to PREVENT corrosion on aircraft and support equipment, the Maintenance Action Form (MAF) is used to document all actions requiring the preparation, treatment, and repair of corroded items, including the painting of areas which have been treated for corrosion. The use of the MAF to document corrosion treatment actions serves to identify the work unit code (WUC) and provides a record of treatment to specific areas for future reference.

Reports

When it is considered necessary to monitor a corrosion control program or investigate how much actual corrective corrosion treatment is being done by an activity, the maintenance data collection system information can be retrieved through the special Corrosion Control/Treatment Report (MDR S-4). This report lists all support action code 040 (corrosion control) and action taken code Z (corrosion treatment) transactions for the month. The report could reveal that one aircraft or component required more attention than others during specific periods. This may be due to where the aircraft has been in relation to other squadron aircraft (deployed, etc.) or may point out a need for a better corrosion program with respect to specific portions of the aircraft, as indicated by WUC's or whenever special operations or deployments are involved.

All instances of material or design deficiency with respect to corrosion should be reported on the Unsatisfactory Material/Condition Report Form, OpNav 4790/47.

Some type commanders encourage the use of aircraft silhouette drawings similar to those illustrating the corrosion-prone areas of specific aircraft in the NavAir 01-1A-509 manual to indicate areas that have received extensive corrosion treatment. On transfer of the aircraft to Progressive Aircraft Rework (PAR) or another reporting custodian, this sheet serves to pinpoint areas that may require additional attention.

BUILT-IN ANTICORROSION PROTECTION

Aircraft design requirements emphasize the strength-to-weight ratio of the various metals used in aircraft construction and relegate corrosion resistance to secondary importance. Selection of corrosion-resistant materials would impose a weight penalty more prohibitive than the cost involved in a program of corrosion prevention by proper maintenance.

In view of the foregoing and the increasing cost of combating corrosion, aircraft manufacturers have been forced to develop and incorporate a variety of built-in anticorrosion features such as surface finishes, pretreatments, sealant and insulating materials, etc., which if properly maintained should provide acceptable corrosion resistance throughout the service life of the aircraft.

PROTECTION OF DISSIMILAR METAL CONTACTS

The use of several types of metals and their alloys in the construction of aircraft requires that some form of protection separator be used to minimize the reaction caused by the differences in electrical potential. Primers, coatings, plastic tape, washers, grease, and sealants are the most commonly used separating materials.

Grouping of Metals and Alloys

The selection of dissimilar metals that are to be used in contact with each other is generally based on the following activity table:

Group I	Magnesium and its alloys.
Group II	Cadmium, zinc, and all aluminum alloys.
Group III	Iron, lead, tin, and their alloys (except stainless steels).
Group IV	Copper, chromium, nickel, silver, gold, platinum, titanium, cobalt and rhodium, stainless steels, graphite (including dry film lubricants containing graphite).

This list groups the common metals and their alloys in the order of their electrical potential. Group I materials are the most active metals and the easiest corroded. Group IV materials are the least active and require only minimum protection.

ELECTROMAGNETIC INTERFERENCE AND CONTROL

The electrical noise interference as described in this chapter is defined as any electrical disturbance which causes an undesirable response or malfunctioning in electronic components or systems, including RF interference. Noise interference enters electronic equipments in many ways. The undesired radiations do not always enter through the receiving systems antenna, although this path is common. Inadequate shielding of antenna lead-in, transmission lines, and receiver front end, and leaky connectors in transmission lines also provide paths of entry. If the equipment housing does not provide adequate isolation, undesired radiation can enter the receiver's intermediate and video frequency circuits. Conductive type interference can also enter the equipment through its power lines. RF interference has grown from a comparatively small problem in the past to become a dangerous threat to the present and future. The trial and error approach to suppression of interference must be complemented or replaced by a scientific approach in both the design and operational phases.

GENERAL SOURCES OF ELECTROMAGNETIC INTERFERENCE

There are three sources of electromagnetic interference (EMI): manmade, natural, and inherent. The first of these three is the major source of concern, and unless given constant attention it can completely destroy man's ability to transmit and receive information via electronic means.

Manmade Interference

Manmade EMI arises from the following sources:

1. Transmitters–These produce spurious emissions due to modulator pulsing; magnetron drift and moding; sideband power due to pulse modulation; harmonic outputs; and arcing in the power amplifier stage, waveguide, rotary joint, or antenna.
2. Electrical controllers–These are associated with electrical installations and have as their function the control of the voltage and/or current fed to (or from) an electrical system. The control system may be a device for continuously and precisely controlling current while producing relatively little interference; or it may be a simple on-off switch resulting in sharp changes in current and causing severe interference over a wide frequency band.
3. Electromechanical devices–Devices such as synchros, blower motors, drive motors and relays are commonly found in electronic equipment, and are all potential sources of noise interference.

MOTORS.–The types of interference generated by d-c motors are:

1. Switching transients as the brush moves from one commutator bar to another. This is usually called commutation interference.
2. Random transients caused by varying contact between brush and commutator. This is usually called sliding contact interference.
3. Radiofrequency and static charges built up on the shaft and rotor assembly.

Direct-current motors used in aircraft systems are of three general types: series wound, shunt wound, and permanent magnet field. The field windings of both series- and shunt-wound motors afford some "padding" or filter action against transient voltages generated by the brushes. The permanent-magnet motor's lack of such inherent filtering makes it a very common source of interference.

It must be emphasized that the size of a d-c motor has little effect upon its interference generating characteristics. The smallest motor aboard may well be the worst offender.

GENERATORS.–The output of an ideal a-c generator is a pure sine wave. A pure sine wave voltage is incapable of producing interference except at its basic frequency. However, the ideal waveform is difficult to produce, especially in small machines.

Practically all types of a-c power generators currently used in naval aircraft are brushless type generators, with less than five percent harmonic content in the worst application. Very little interference is generated at the power source.

It should be noted also that a-c motors that do not use brushes are almost never sources of interference.

Manmade interference originating from other types of electrical or electronic components may be classified as either conducted or radiated, depending on the mode of transmission.

RADIATION INTERFERENCE.–Radiation interference is any undesirable RF signal which reaches a receiver by direct radiation and degrades its performance. This may be caused by poorly shielded radar modulators, RF energy escaping from waveguide flange couplings, commutators, relays, or cochannel or adjacent channel transmitter outputs.

CONDUCTED INTERFERENCE.–Conducted interference is any undesired signal which reaches a receiver by direct, inductive, or capacitive coupling through the antenna lead-in cable, power leads, signal leads, or control circuits.

Natural Interferences

Types of interference caused by natural phenomena are those such as electrical storms, rain particles, and interstellar radiation. This type of interference has a greater effect on radio communication than on radar operation.

Inherent Interference

Interference is inherent in the design of receiving equipments. This factor, brought about by the random motion of free electrons in a conductor, causes small potential difference to be developed across the terminals of the conductor. This action, called thermal agitation, is a common source of background noise. Inherent interference is of great concern in radar operation.

Electron tubes act as a source of noise because of the nature of their operation. They cause a noise commonly called "shot" effect. Shot effect is created by electrons being emitted from the cathode in a random way so that any current resulting from such emission has a random variation.

Components that transfer energy in the form of heat are interference generators. However, interference of this nature is unavoidable.

Types of Electromagnetic Interference

Electromagnetic interference can be classified according to spectrum distribution, namely, broadband and narrowband.

NARROWBAND INTERFERENCE.–Narrowband interference consists of a single frequency or a narrow band of frequencies that occupies little space in the receiver passband. Another way of defining narrowband signals is that they are unaffected by the bandwidth of the receiving device; i.e., they are narrow with respect to the receiver bandwidth. An interfering narrowband signal can sometimes be prevented from causing an undesired response by tuning the susceptible receiver away from it; however, even out-of-band signals may interfere if they are strong enough to force their way past the attentuation of the RF stages.

BROADBAND INTERFERENCE.–Broadband interference is not of a discrete frequency nature; i.e., it occupies a relatively large part of the frequency spectrum. It is not usually possible to tune away from it since it is much wider than either the assigned frequency channel or the receiver bandwidth. This type of interference is usually caused by arcing.

RADAR SYSTEMS INTERFERENCE

Primary sources of interference in radar equipments are the modulator, transmitter, and electromechanical devices.

Modulators

Thyratrons, which are common in modulator switching application, radiate large quantities of electromagnetic energy while in operation. These radiations will cause interference if proper shielding is not practiced; however, the main source of interference in a modulator is its own output waveform.

This waveform is a high-voltage rectangular pulse which causes the generation of harmonics over a broad portion of the frequency spectrum. Any extraneous voltage spikes on the waveform will necessarily increase the related interference level. Since most radar transmitters require a modulation pulse with fast rise and fall times, very little can be done to prevent the generation of harmonics. Since little can be done to prevent the generation of interference produced from the modulator pulse, the interference produced therein must be isolated by shielding from other electronic equipment.

Magnetrons

Magnetrons are self-excited oscillators that emit energy at harmonics of the fundamental frequency and also at spurious frequencies that bear no relation to the fundamental. The most commonly used microwave power source is the pulse-modulated magnetron, and it is also the most troublesome from an interference standpoint. The harmonic and spurious output level is unpredictable and will vary between tubes of the same design.

Since the causes of harmonic and spurious emissions are not fully understood nor their effects easily predicted, a filter is usually placed between the transmitter and the antenna to attentuate harmonic and spurious outputs.

When the radar antenna is scanning, it is inevitable that variations in magnetron loading will occur as a result of changing reflections from rotary joints, antenna housing, and nearby large reflecting objects. Such changes in loading, produce changes in frequency which may be large. The effect of loading on the frequency of a magnetron is usually expressed by what is called the "pulling figure." It is defined as the total frequency excursion experienced when a voltage with a standing wave ratio of 1:5 to 1 is presented to the magnetron and varied in phase over at least 180°.

The problem of pulling of the magnetron frequency due to variation in load is attacked in two ways: (1) the magnetron is designed so that its frequency shift with changing RF loading is small; and (2) variations in RF loading are reduced by careful design and construction of the RF components.

It is possible in some cases to combine a high-Q cavity with the magnetron coupled to it in such a way as to reduce the pulling figure by a large amount with little or no loss in efficiency. The addition of this stabilizing cavity has the disadvantage of reducing the tuning range of the magnetron.

Waveguides

Leakage of RF power can occur at any waveguide or coaxial cable joint. Leakage from waveguide joints constitutes an interference source and also a loss in transmission efficiency.

To minimize leakage the waveguide should be firmly connected with an RF shielding gasket between sections. The bolts holding the waveguide joints together should be external to the high intensity RF area. The gasket is usually located between the bolt holes and the RF area. A short section of flexible waveguide is normally used in connecting the waveguide to the transmitter to adjust for slight misalinement of the waveguide and transmitter.

Duplexers may use gas TR (transmit-receive) and ATR (anti-TR) tubes or ferrite devices. The TR and ATR tubes function as switches through ionization of their internal gases during the transmit time. The ionization process produces interference which may be conducted or radiated to other equipments. If the tubes require a "keep-alive" voltage, the "keep-alive" voltage lead should be filtered and shielded.

Another kind of interference, often difficult to detect, is the broadband noise due to arcing or corona. Arcing may result when a rotary joint is dirty, worn or misalined. This is a cumulative process since arcing causes further deterioration of the joint which results in more arcing. Substained arcing normally causes a complete breakdown of the rotary joint. Arcing can occur also in waveguides due to foreign objects (including moisture) in the waveguide, corroded or flaked-off coating, a high voltage standing-wave ratio (VSWR), or a sharp bend in the waveguide run.

Local Oscillator Radiation

The local oscillator input to the mixer is at least 10 times the magnitude of the desired signal input. This ratio is desirable for good conversion efficiency to the intermediate frequency. In most radar receivers, the high frequencies used preclude an RF amplifier stage ahead of the mixer. The result is that the strong local oscillator signal is fed back to the antenna system and is radiated as an interfering signal. A major disadvantage of local oscillator radiation is its capability of detection by enemy ECM equipment even when the RADAR is not transmitting. A secondary consideration, at least in the radar frequencies, is the possibility of this signal interfering with nearby receiving equipment.

Usual fixes for this kind of interference include:

1. Use of a balanced mixer which greatly attenuates the local oscillator signal leaking through to the antenna.
2. Proper shielding and filtering of the local oscillator stage including components and wiring.

Radar To Radar Interference

An often-encountered type of interference to a radar system is the interference that is generated by another radar system operating near the same frequency of the affected radar. This will appear on the affected radar indicator. The effectiveness of a radar is reduced if visual displays are obscured by this type of interference. Information pertinent to interference identification can be obtained from a close examination of the radar indicator. Radars employing intensity modulation may be used to indicate two or three dimensions. Pulse type interference is usually observed as a pattern of dots varying in number and intensity. The number of, and relative movement of, these dots are indications of pulse recurrence frequency of an interfering signal relative to the sweep rate of the indicator. An indicator may show a single band of dots similar to a range mark if the PRF of the interfering signal is equal to the sweep rate or multiples of the sweep rate. The position of the interference ring on the plan-position indicator will be determined by the time of arrival of the interference pulse in relation to the starting time of each trace on the indicator.

When the PRF of an interfering signal and sweep rate of an indicator are different and not related by a multiple, the interference becomes apparent as spirals or disarranged dots. Thus, the interference does not appear at the same point, relative to the start of each indicator sweep line. Continuous wave type interference is characterized by its appearance as a solid sector or area of high intensity. A detailed examination of arrangement of the interference pattern structure on a radar indicator is helpful in determining the number of interference signals present. Since it is rare that any two pulse recurrence frequency rates are identical, each interference signal will show a different pattern. Interfering signals are quite often of different amplitude and may cause a corresponding difference on the radar indicator. Careful observation and adjustment of receiver gain controls may prove helpful in distinguishing the number of interference signals when more than one are present.

ELECTROMAGNETIC INTERFERENCE REDUCTION

There would be no need for EMI reduction methods if aircraft equipment design, manufacture, and installation were accomplished in such a manner as to anticipate and eliminate all potential interference situations. Although this may be an ideal goal, it is not yet fully realizable. Therefore, EMI reduction techniques are still necessary.

Suppression Methods

Isolation is the easiest and most practical method of suppression, and revolves around the possibility of physically separating the source of noise from the input circuits of the receiving equipments affected. As every manmade RF noise source can be considered a small transmitter, it is obvious that the noise source and the leads carrying noise energy should be kept as far away from receiver antennas or lead-ins as possible.

The value of sufficient separation between sources of RF noise and receiver input circuits is not apt to be overemphasized. The isolation method of noise suppression has the advantages of not requiring any additional material or adding any additional weight.

Bonding is a very important means of interference control. It provides grounding of insulated conducting objects on the exterior of the aircraft. When conducting objects are not grounded, flight through precipitation causes high-voltage charges to build up on those objects. Repeatedly, the voltage gets high enough to spark over to an adjacent ground member or the object discharges to the surrounding air by corona conduction. Either mode of discharge causes considerable interference.

Other important functions of bonding are:

1. To protect the aircraft and personnel from lightning discharges by equalization of potentials

which might cause arcs and sparks in the aircraft structure.

2. To provide a homogeneous counterpoise for radio transmission and reception.

3. To provide a short path for bypassing RF noise.

All electronic equipment should be grounded to the aircraft structure. This should be done by using short bond straps or sheets of high conductivity (copper or aluminum) metal where it is impossible to use bond strap. No bond strap should be more than 4 inches in length.

Shielding is one of the most effective methods of suppressing noise. The primary object in shielding is to electrically "bottle up" the noise energy. In practical application, this means that the RF noise energy must be kept flowing along the inner surface of the shield. The use of good shielding is particularly effective in situations where filters cannot be used. A good example of this is where noise energy radiates from an RF noise source and the radiated energy is picked up by the various circuits that eventually connect to the receiver input circuits. It is obvious that it would be impractical to filter a number of leads or units that are influenced by the noise energy; hence, the application of effective shielding at the noise source itself is advisable for it will eliminate the radiated portion of the noise energy by confining it within the shield at its source.

RF interference as radiated or conducted from a source may be of a single frequency or may cover an extended band of frequencies, as previously mentioned. When bonding, shielding, or isolation of the source proves ineffective as a means of reducing this interference, it becomes necessary to employ filters to accomplish the reduction. A filter is defined as a selective network which transmits freely electric waves having frequencies within one or more frequency bands and which attenuates substantially electric waves having other frequencies.

The size of a filter may vary widely, depending on the voltage and current requirements as well as the degree of attenuation desired. Filters are usually incorporated in equipment known to generate RF interference, but these filters are often inadequate, and in many cases it is necessary to add filters external to these equipments. This is especially true if the source or interference is coupling interference to paths of entry to a receiver other than the powerline.

The types of filters used in the reduction of interference vary with the application, but each of the general filter types may be found to be particularly adaptable to some specific situation. Most of the electrical devices connected to powerlines have features required for their operation, which are conducive to the generation of interference.

The interference generated by these devices, unless properly attenuated, is impressed upon the powerlines and conducted to the receivers. It may also be conducted into the receivers by inductive coupling to other wiring associated with the receivers. This interference, unless attenuated by means of filters, is then transmitted along these powerlines, entering the receivers at the powerline input; or this interference may be radiated along the powerlines and enter the receiver by means of the antenna system.

Filters are of four kinds and are defined as follows:

1. The low-pass filter, which introduces negligible attenuation at all frequencies below a certain frequency, called the cutoff frequency, and relatively high attenuation at higher frequencies.

2. The high-pass filter, which introduces negligible attenuation at frequencies above a certain frequency, called the cutoff frequency, and relatively high attenuation at lower frequencies.

3. The bandpass filter, which introduces negligible attenuation at all frequencies within the range between two frequencies, and relatively high attenuation at other frequencies.

4. The band elimination filter, which introduces negligible attenuation at all frequencies outside a certain range, and relatively high attenuation at frequencies inside that range. The normal characteristics of a filter are obtained only when the filter is properly terminated in its characteristic impedance.

A wave trap is a filter or network especially designed to reject certain frequencies, or bands of frequencies. Networks of this type may be installed at the antenna of the transmitter or receiver in order to attenuate frequencies outside of the assigned frequency range of the equipment. All such networks must have low insertion loss, or attenuation, for the pass frequencies. In the design and construction of wave traps, the insertion loss is usually below 2 db.

From the discussion in the preceding paragraphs it can be seen that equipment design is the prime factor in elimination and control of noise interference. It is also obvious that the responsibility of the AQ for detecting and maintaining control of interference is not limited to the equipment for which he is directly responsible, since operation of fire control equipment will no doubt also affect other systems. In fact many times radio interference is traced directly to fire control equipment. All maintenance personnel must be on the alert for possible sources of interference and must maintain the equipment in its original design configuration. This is especially important where shielding and bonding are concerned, since bonding and shielding are often disturbed during maintenance procedures. This is especially true during installation of changes in an equipment where rerouting of leads and cables, or the installation of new leads or cables is required.

CHAPTER 5

AVIONICS SUPPORT EQUIPMENT

For effective operation of an aviation fire control system, it is imperative that its radar set operates at its maximum effectiveness within its designed limits. To accomplish this the technician must employ the best maintenance techniques and utilize the support equipment to the utmost.

The following discussion on the operation of various support equipments is designed to aid in furthering knowledge of these support equipments and their use in effective maintenance of aviation fire control systems. The technician should bear in mind that this discussion is not a substitute for the support equipment's Operating and Maintenance Instruction Manual, which should be consulted before operating any type of support equipment.

SPECTRUM ANALYZER SA-84WA

The amplitude of individual frequencies which make up a signal when plotted against frequency is termed the specturm of a signal. Various types of equipment provide a visual indication of the spectrum. Those equipments used for observation of the spectra of RF oscillators are called spectrum analyzers. The spectrum analyzer discussed in this chapter is the SA-84WA.

THEORY AND ANALYSIS OF A SPECTRUM

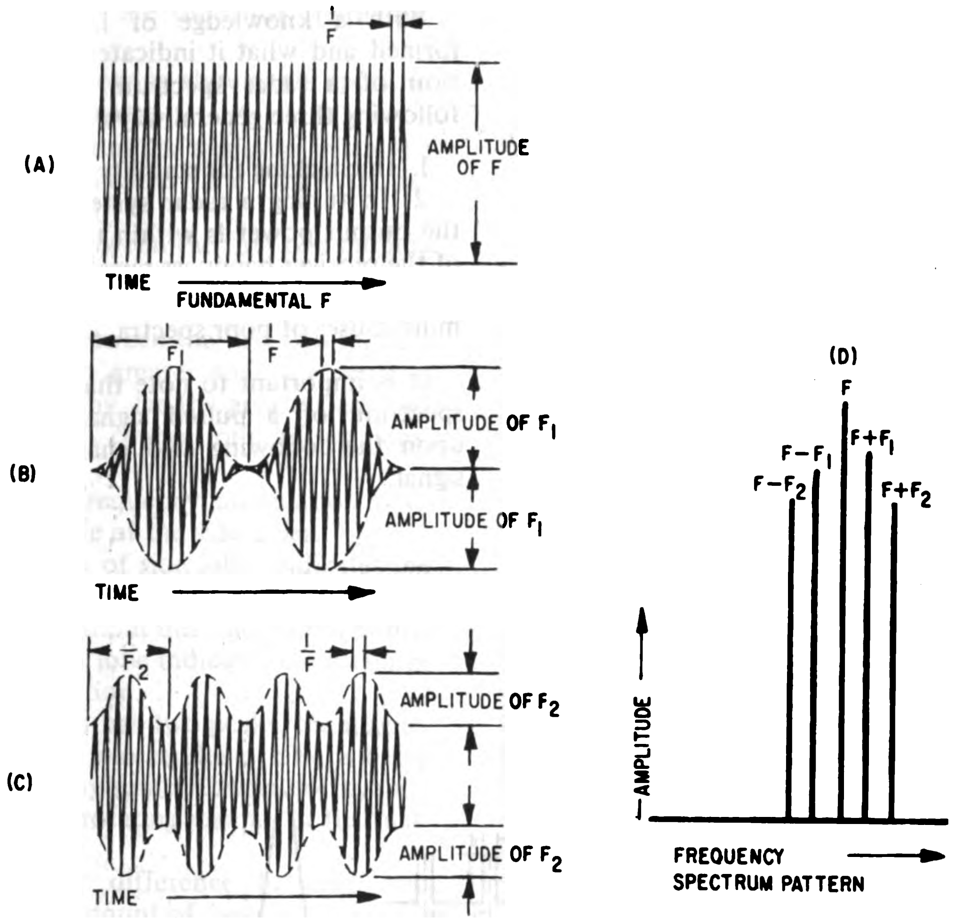
Prior to a discussion on the operation of the SA-84WA and for a better understanding of the test set in general, a brief discussion on the basic principles, application, and practical value of a spectrum analysis is given in the following paragraphs.

Basic Principles

In conventional circuit theory, any repetitive waveform can be analyzed by the use of Fourier equations. This type of analysis shows that a square wave, or any other nonsinusoidal repetitive wave, consists of a fundamental sine wave plus an infinite number of harmonics. The pulsed output of a radar transmitter can be treated in the same manner.

The process of modulation inherently produces frequencies other than the modulated or modulating frequencies themselves. When the frequencies resulting from a modulation process are plotted on a horizontal scale and the energy distribution among these frequencies is plotted on a vertical scale, the result is a frequency power plot, more commonly known as a spectrum. Figure 5-1 (D) illustrates the spectrum resulting when a fundamental frequency F is modulated by arbitrarily chosen frequencies F_1 and F_2. Actually there are an infinite number of frequencies present even in the simple modulation of one sine wave by another, but the amplitudes of the higher order harmonics are negligible.

If the fundamental frequency F (fig. 5-1 (A)) is modulated by F_1, the resultant wave form will appear as illustrated in figure 5-1 (B). In the spectrum pattern (fig. 5-1 (D)), the modulation by F_1 causes two other frequencies to appear. $F + F_1$ and $F - F_1$, respectively. It is suggested that you read the section entitled modulation principles contained in chapter 22 of Basic Electronics Vol I, NavTra 10087-C.



AQ.326
Figure 5-1.—Formation of a spectrum.

Figure 5-1 (C) shows the effect of modulating the fundamental frequency F with a frequency F_2 which is twice the frequency of F_1. The result is the appearance of two new frequencies in the spectrum which are indicated as $F + F_2$ and $F - F_2$.

Application of Principles to a Pulsed Oscillator

Although the duration of a pulse is extremely small compared to the repetition rate in a typical radar system, the output can be visualized for purposes of analysis as a continuous wave of RF energy which is periodically interrupted. This in effect is the same as taking the continuous RF wave and modulating it with a repetitive rectangular pulse. Since the pulse itself contains an infinite number of harmonics of its own repetition frequency, each of these harmonic frequencies and the repetition frequency modulate the continuous wave. Hence, a spectrum evolves in the manner explained in the preceding discussion except that there are an infinite number of sideband components.

Figure 5-2 (A) illustrates a theoretical voltage spectrum of a pulsed oscillator. Though not shown, an infinite number of negligibly small sideband components extend from either side of the limits of the diagram. Any two adjacent sideband components are separated by a distance on the frequency scale which is equal to the repetition rate of the rectangular pulses (fig. 5-2 (B)), because each component bears a harmonic relationship to the repetition frequency.

Neither of the voltage spectra shown in figure 5-2 (A) and (C) is actually seen on the test set scope because of a square-law detector incorporated in the test instrument. This detector converts the voltage into the power spectrum illustrated in figure 5-2 (D).

Practical Value of Analysis

With a knowledge of how a spectrum is formed and what it indicates, a visual examination of a radar spectrum is valuable in the following three general ways:

1. In checking for stability of a magnetron.
2. In tuning a radar system so that most of the output power is within the frequency range of the receiver bandpass response.
3. In analyzing radar system outputs to determine causes of poor spectra.

It is important to note that the shape of the spectrum of a pulsed signal depends chiefly upon the following two characteristics of the signal:

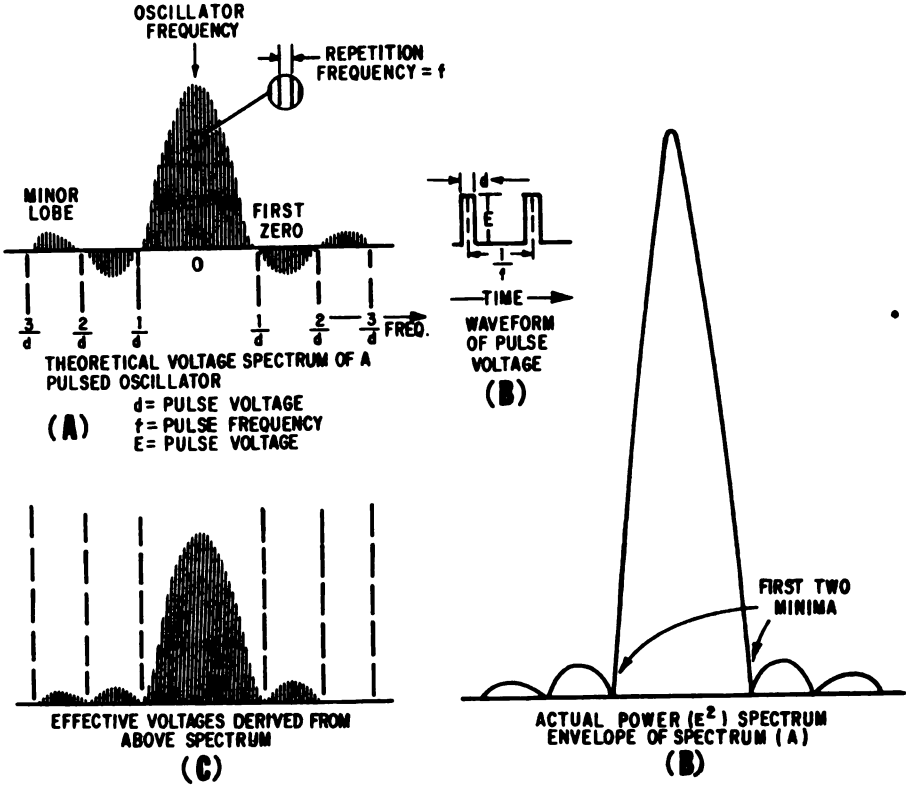


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Figure 5-2.—Conversion of a voltage spectrum to a power spectrum.

1. The modulation envelope of the pulse.

2. The shifting of the oscillator frequency during the pulse.

In general, the following statements apply in the analysis of a spectrum:

1. The ideal spectrum is achieved when the pulse is truly rectangular and there is no frequency modulation.

2. The distance between the first two minima of an ideal spectrum is a measure of the pulse width of the signal.

3. The distance between the first two minima should not be much greater than the receiver bandwidth, because by far the greatest amount of power is in the center lobe of an ideal spectrum.

4. An effect of frequency modulation is to increase the amplitude of the side lobes.

5. A large number of side lobes indicates the presence of amplitude modulation.

6. A spectrum without deep minimum points adjacent to the main lobe indicates the presence of frequency modulation.

7. If the spectrum has two peaks, the magnetron is operating in two modes or else is being pulled in frequency by some external force, such as a poorly matched rotating scanner or fluctuating voltages.

8. The frequency difference between two peaks indicates the amount of frequency pulling. The height indicates the relative power at the frequency of each peak.

Figure 5-3 illustrates various types of spectra that may be observed on the CRT screen of the SA-84WA spectrum analyzer. These types of pictures may be observed when checking the spectrum of pulsed magnetron oscillators. The display will indicate the pulse width, pulse shape, and the amount of amplitude or frequency modulation on the pulse. In this way the SA-84WA may be used to determine the extent and type of modulation present in a CW signal or a pulsed signal.

PURPOSE OF THE SA-84WA SPECTRUM ANALYZER

The SA-84WA spectrum analyzer is a wide dispersion spectrum analyzer which provides a rapid and accurate spectral display of the frequency distribution of energy present in RF signals over the frequency range from 10 MHz to 63,680 MHz. The spectrum analyzer and its accessories are shown in figure 5-4. The spectrum of CW or modulated RF signals is displayed on the horizontal axis of the cathode-ray tube screen while the signal voltage is plotted along the vertical axis. Also provided is a choice of dispersion bandwidths for the analysis of narrow or wide pulsed RF signals as well as a variable resolution for a detailed spectrum of the signal.

The general applications of the spectrum analyzer are as follows:

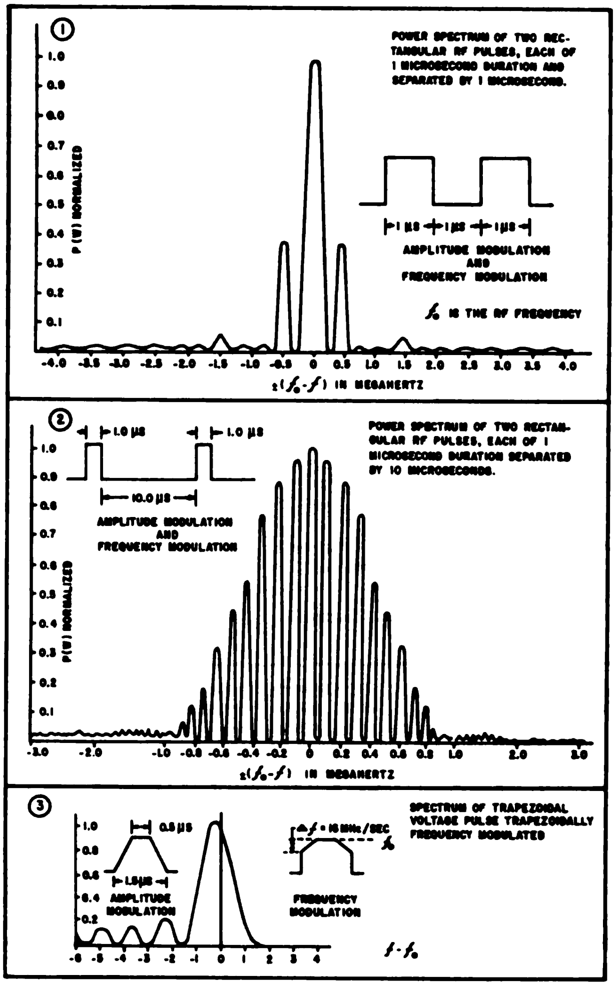

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Figure 5-3.—Representative spectra in signal analysis.

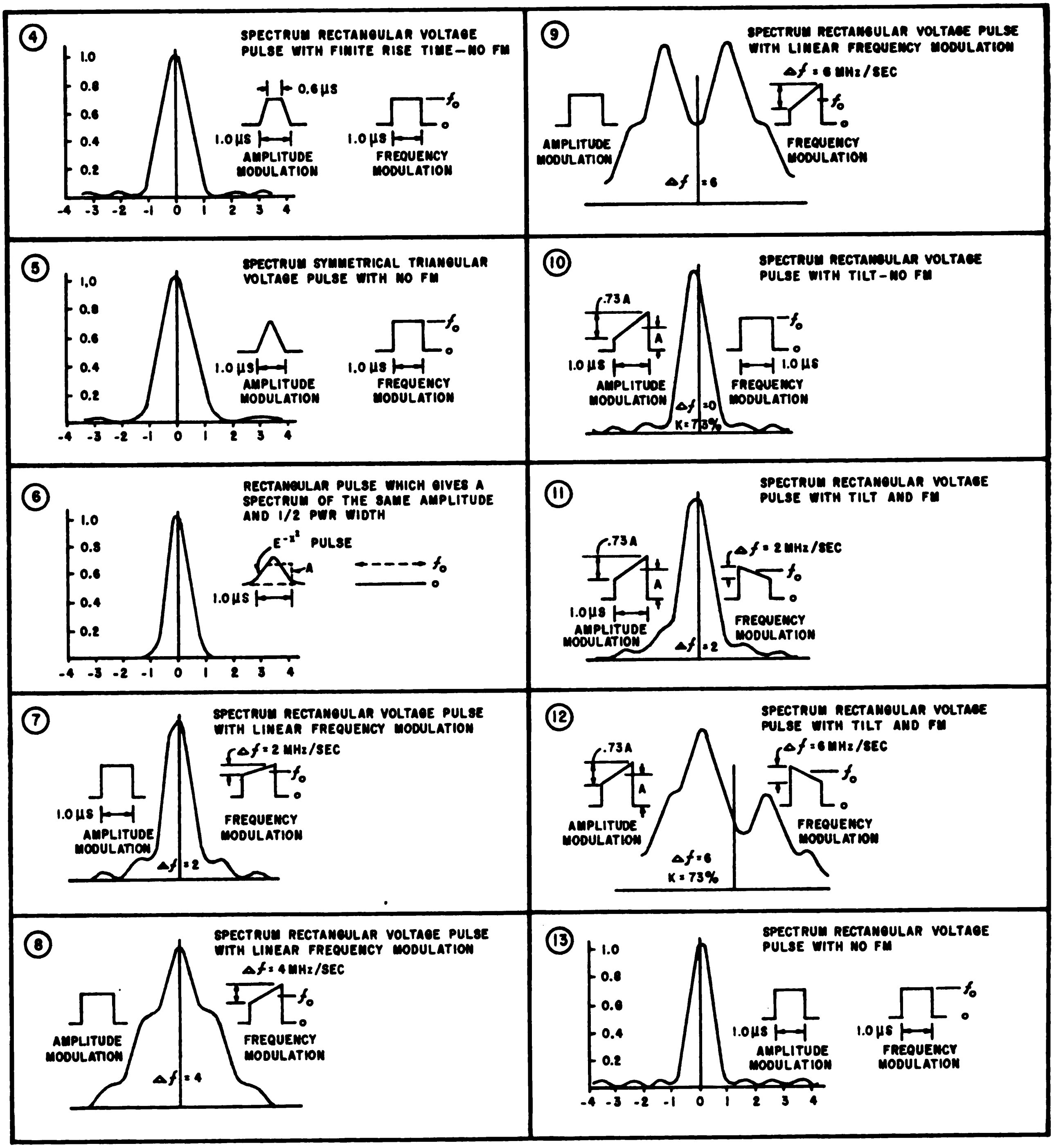

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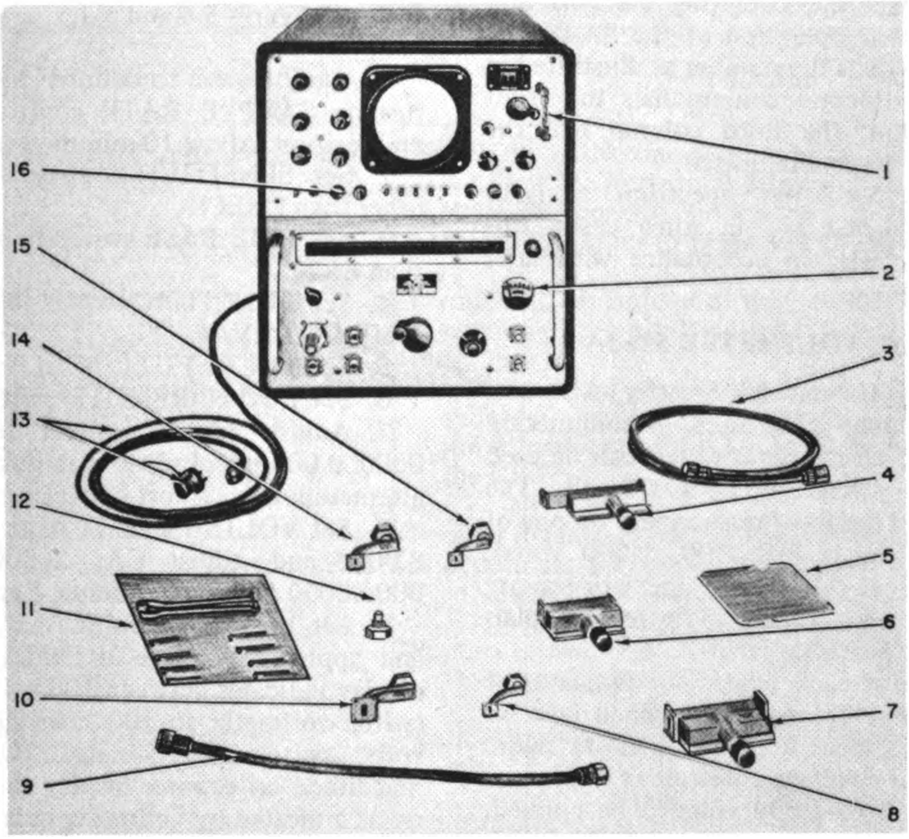
Figure 5-3.—Representative spectra in signal analysis—Continued.



1. IF cable assembly. (Connected from Preamp output to IF input.)
2. Tuning unit.
3. RF cable assembly.
4. Ka band attenuator.
5. CRT filter.
6. K band attenuator.
7. Ku band attenuator.
8. Q band attenuator.
9. RF cable assembly.
10. Waveguide (Ku band) to mixer adapter.
11. Wrench kit.
12. Type N to mixer adapter.
13. Power cable assembly with adapter.
14. Waveguide (K band) to mixer adapter.
15. Waveguide (Ka band) to mixer adapter.
16. SA-84WA spectrum analyzer.

AQ.4

Figure 5-4.—Model SA-84WA spectrum analyzer and components.

1. Observing and measuring the sidebands associated with amplitude and frequency-modulated RF signals.

2. Determining the presence of radar signals within the frequency range of 10 MHz to 63,680 MHz.

3. Determining the type of radar signal modulations.

4. Checking and observing the tracking of radar system components.

5. Checking the spectral characteristics of wide and narrow RF pulses.

6. Measuring noise spectra.

7. Precisely measuring RF signals having a relatively wide frequency separation.

8. Providing a secondary frequency standard for the measurement of high and low level signal frequencies.

9. Providing a sensitive indicator of voltage standing wave ratio measurements.

OPERATING PROCEDURES

Table 5-1 lists the operating controls and indicators used in operation of the SA-84WA. The left column lists the number as illustrated in figure 5-5; the second column lists the front panel designation; the third column lists the function of the control indicated.

NOTE: The SA-84WA spectrum analyzer controls are labeled MC in some cases; this discussion uses MHz in accordance with later standards.

DIGITAL VOLTMETER 5265A

The digital voltmeter 5265A (fig. 5-6) is a plug-in unit which, when used in conjunction with the 5245L electronic counter, can be used to measure d-c voltages up to 1,000 volts. The digital voltmeter permits measurement on one of three voltage ranges (10, 100, 1,000 volts), provides a manual selection of local or remote operation, and automatically indicates the polarity of the input d-c voltages.

The purpose of each control or indicator of the digital voltmeter can be explained best by referring to the identifying numbers on figure 5-6. The input d-c voltage connector (1) allows a d-c voltage of 0 to 1,000 volts to be applied, depending on the position of the VOLTS FULL SCALE switch. The VOLTS FULL SCALE switch (2) is used to select the correct range for the input d-c voltage. The LOCAL/REMOTE switch (3) is used to determine whether the operation is controlled directly from the voltmeter (LOCAL) or from a remote location (REMOTE). Control number 4 is used for obtaining zero adjust. With the VOLTS FULL SCALE switch set on 1,000, adjustment is made until 000000.00 appears on the counter display. Number 5 is the CAL 8.000 adjustment—with the VOLTS FULL SCALE switch set to CAL 8.000, the control is adjusted for a readout of 8.000 on the counter display. The plus and minus polarity indicators (6) are neon lights that automatically indicate the polarity of the input d-c voltage.

OPERATING PROCEDURES OF THE 5265A DIGITAL VOLTMETER

Figure 5-7 is a picture of the Digital Voltmeter 5265A installed in the Electronic Counter 5245L. A step-by-step operating procedure for both the voltmeter and counter is given below. Refer to figures 5-6 and 5-7.

1. Apply power to counter and voltmeter by turning SAMPLE RATE control clockwise to midposition. Allow 10-minute warmup.
2. Set SENSITIVITY switch to a position other than CHECK.
3. Set TIME BASE switch to a position other than EXT.
4. Set FUNCTION switch to REMOTE OR TIME INTERVAL.
5. Set VOLTS FULL SCALE switch to 1000.
6. Set LOCAL-REMOTE switch to LOCAL.
7. Adjust ZERO control for display of 000000.00 and observe that polarity indicators alternately flash. Short INPUT terminals.
8. Set VOLTS FULL SCALE switch to CAL 8.000, and adjust CAL 8.000 control for 0008.0000 display ±5 counts. Remove short.
9. Set VOLTS FULL SCALE switch to 1000 and apply DC voltage at INPUT terminals. (If display indicates between 100 volts and 10 volts, switch voltmeter to 100 range. If less than 10 volts, switch to 10 range.) Observe voltage magnitude on counter display and voltage polarity as indicated by voltmeter polarity neon.

OSCILLOSCOPE TYPE 453

The Tektronic Type 453 Oscilloscope is a lightweight, transistorized portable oscilloscope which provides the performance necessary for high frequency measurements. It has a single- and dual-channel vertical deflection system which operates between d.c. and 50 MHz with a calibrated deflection factor ranging from 5 millivolts to 10 volts per graticule division. The two channels may be cascaded to provide a 1 millivolt minimum deflection factor. Stable triggering is provided over the entire vertical frequency response.

The horizontal sweep provides a maximum sweep rate of 0.1 μsec per division along with a delayed sweep feature for accurate relative time measurements.

The regulated d-c power supply operates on either 115 volts a.c. or 230 volts a.c. with line frequencies of 45 to 440 Hz. The power consumption is approximately 100 watts.

Table 5-1.—Operating controls, indicators, and connectors; SA-84WA.

Figure 5-5 Index No.	Front panel designation	Function
1	HOR GAIN control and HOR POS control	The HOR GAIN control permits the varying of the width of the horizontal display on the CRT. The HOR POS control permits the display on the CRT to be shifted either to the left or to the right.
2	INTFR control	Permits the adjustment of the intensity of the signal portion of the display only.
3	VERT POS control and VERT GAIN control	The POS control permits the display on the CRT to be shifted either up or down. The GAIN control permits the adjustment of the height of the vertical display on the CRT.
4	SYNC control	Permits the adjustment of the synchronizing voltage, permitting the phantastron generator to lock at submultiples of the line frequency.
5	IF ATTENUATOR DB switches	Permits attenuation of the vertical display in 1-db steps from 0 to 20 db.
6	BRIGHTNESS control	Varies the brightness of the trace on the cathode-ray tube.
7	SCALE ILLUM control	Controls the illumination of the CRT graticule.
8	CRYSTAL CALIBRATOR MC switch	Permits the selection of either the 1, 10, 50, or 100 MHz calibration pips.
9	DIFFERENCE FREQUENCY MCS TUNING control and FREQUENCY DIFF-MCS dial.	Rotation of the DIFFERENCE FREQUENCY MCS TUNING control permits the location of the marker pip within ±40 MHz of the IF bandpass center frequency. Variation from the IF bandpass center frequency is indicated on the FREQUENCY DIFFERENCE MCS dial.
10	IF INPUT jack	Provided for applying either the output of the preamplifier or an external test signal to the display unit circuitry.
11	PREAMP OUTPUT jack	Provided for access to the output of the preamplifier. It also permits the use of the Polarad Model SD-1 Multipulse Spectrum Selector, which makes it possible for the SA-84WA to analyze individual pulses in a pulse group.
12	MARKER AMPLITUDE control	This control, when rotated clockwise beyond its OFF position, permits the adjustment of the height of the marker pip on the CRT.

Table 5-1.—Operating controls, indicators, and connectors; SA-84WA—Continued.

Figure 5-5 Index No.	Front panel designation	Function
13	BANDWIDTH control	Permits the varying of the resolution bandwidth from 1 to 80 KHz.
14	SYNC INPUT jack	Provided for the application of an external synchronizing (signal with the SYNC SELECTOR switch in the EXT position) to the phantastron generator.
15	SYNC SELECTOR switch	Permits the selection of either internal or external synchronization of the phantastron generator. When in the OFF position, the phantastron generator is free-running.
16	BAND SELECTOR switch and FREQUENCY dial	Selects the proper scale on the frequency dial drum and indicates the frequency being measured.
17	ATTENUATOR INPUT 2000-12,400 MC jack	Provided for the application of high-level incoming RF signals (greater than −20 dbm).
18	ATTENUATOR INPUT 10-2240 MC jack	Provided for the application of high-level incoming RF signals (greater than −20 dbm).
19	RF ATTENUATOR control	Permits the attenuation of incoming RF signals which are applied to either the ATTENUATOR INPUT 10-2240 MC jack or the ATTENUATOR INPUT 2000-12,400 MC jack. The attenuation inserted by this control is variable between 0 and 100 db.
20	TUNING control	Adjusts the frequency of the signal displayed on the CRT.
21	ATTENUATOR OUTPUT 10-2240 MC jack	Provided to couple the output of the RF attenuator to the DIRECT INPUT 10-8, 900 MC jack.
22	ATTENUATOR OUTPUT 2000-12,400 MC jack	Provided to couple the output of the RF attenuator to the DIRECT INPUT 6,300-63,680 MC jack.
23	DIRECT INPUT 10-8,900 MC jack	Provided for the direct application of incoming RF signals. This connection utilizes the maximum sensitivity of the SA-84WA.
24	DIRECT INPUT 6,300-63,680 MC jack	This coaxial jack is provided for the application of incoming RF signals. This connection utilizes the maximum sensitivity of the SA-84WA.
25	METER SELECTOR switch and Power Monitor meter	This six-position rotary switch, in conjunction with the monitor meter, monitors the various operating voltages and the first crystal mixer current as follows:

Table 5-1.—Oparating controls, indicators, and connectors; SA-84WA—Continued.

Figure 5-5 Index No.	Front panel designation	Function
		a. REFLECTOR position–monitors the high-frequency local oscillator reflector voltage. b. LINE position–monitors the power line voltage. c. +125 position–monitors the +125 volt supply. d. +300 position–monitors the +300 volt supply. e. XTAL position–monitors the first crystal mixer current. f. METER OFF position–the monitor meter is not connected into the circuit.
26	LOG-FILTER-LIN switch	Permits the selection of logarithmic, logarithmic-filter, linear-filter or linear vertical deflection on the cathode-ray tube. The filter positions introduce a video filter in the circuitry.
27	POWER pilot lamp	Indicates that the SA-84WA is energized.
28	Power ON-OFF switch	Energizes the SA-84WA.
29	FOCUS control	Adjusts the sharpness of the CRT display.
30	SWEEP SPEED control	Permits the control of the sweep repetition rate, which can be varied from 1 to 30 Hz.
31	CENTER FREQUENCY COARSE and FINE controls	Permit adjustment of the center frequency of the sweep-frequency generator to position the display at the electrical center of the CRT.
32	DISPERSION HIGH-LOW switch and DISPERSION CONTROL	The switch selects the dispersion range. NOTE: When the BAND SELECTOR switch is in the Band 1 position, the dispersion is limited to 10 MHz. The control permits the adjustment of the display dispersion (amount of frequency displayed) as follows: a. When the DISPERSION switch is in the LOW position, the dispersion can be adjusted from 25 KHz to 10 MHz. b. When the DISPERSION switch is in the HIGH position, the dispersion can be adjusted from 1 to 80 MHz.

Table 5-1.--Operating controls, indicators, and connectors; SA-84WA--Continued.

Figure 5-5 Index No.	Front panel designation	Function
33	LOG ZERO adjustment	Adjust baseline in LOG position so that there is no baseline shift when switching from LIN to LOG.
34	VIDEO OUTPUT connector	Provides a video signal for external use.
35	SWEEP OUTPUT connector	Provides a sweep signal for external use.

The input impedance with direct coupling is about 1 megohm in parallel with 20 pf capacitance.

Figure 5-8 is a picture of the front, side, and rear panels of the oscilloscope discussed.

PREPARING THE OSCILLOSCOPE FOR VIEWING (TRACE)

The intensity control (INTENSITY), which controls the brilliance of the sweep, varies the grid bias on the cathode-ray tube (CRT). The focus control (FOCUS) varies the potential on the focus grid. The focus and intensity interact and therefore must be adjusted together. The astigmatism adjustment (ASTIG) varies the positive level on the astigmatism grid and allows the vertical and horizontal portions of the sweep to be sharply focused at one setting of the focus control. A trace alinement control (TRACE ROTATION) provides for the rotation of the trace to a horizontal position by varying the magnetic field around the CRT. A trace finder switch (TRACE FINDER) allows the operator to decrease the overall size of the viewed signal in cases where the vertical and/or horizontal signals are so large in amplitude that they overscan the viewing area.

VERTICAL DEFLECTION CAPABILITIES

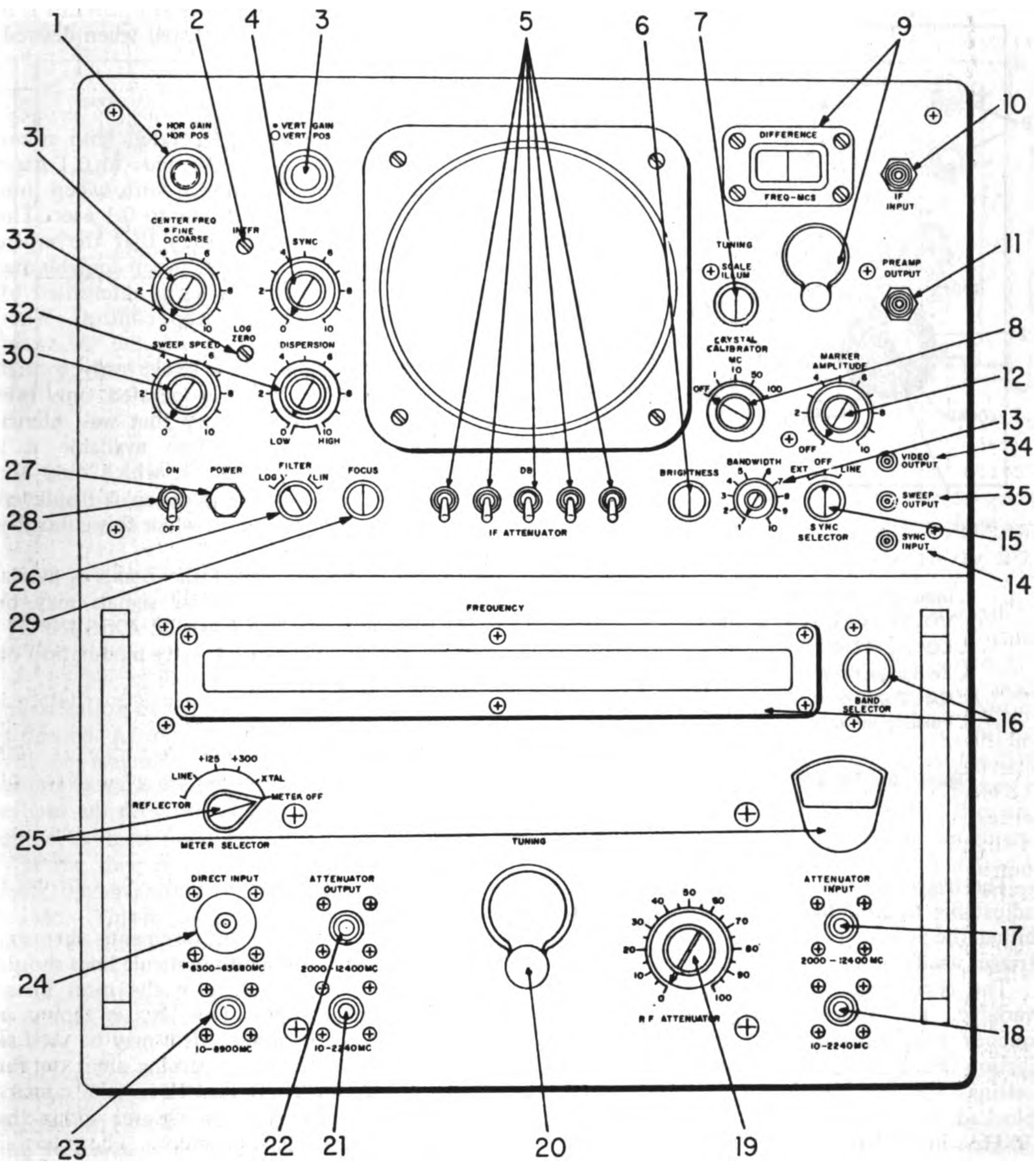
The two channels (1 & 2) may be operated independently or together. Each channel has its own positioning control which moves the horizontal trace either up or down. The vertical deflection for each channel is controlled by a volts/division switch (VOLTS/DIV) and a variable control (part of VOLTS/DIV control). Each channel has its own input coupling (AC, GND, DC).

A mode selector (MODE) allows the operation of channel 1 only (CH 1), channel 2 only (CH 2), alternate (ALT) (which gives a dual trace display of signals on both channels), CHOP (which gives a dual trace display of signals on both channels), or ADD (channel 1 & 2 signals are added and the algebraic sum is displayed). The difference between ALT and CHOP is that in ALT the signals are changed at the end of each sweep and in CHOP the signals are switched by having a 1 μsecond segment from each channel displayed at a repetition rate of 500 KHz. The channel 2 signal may be inverted at any time.

Each channel may be triggered from the signals displayed or the vertical sweep circuits may be triggered from the display on channel 1 only.

TRIGGERING CAPABILITIES

There are three sources for triggering the A and B horizontal sweeps. These are external (EXT), LINE, and internal (INT). The external trigger inputs are connected through the jacks for the appropriate sweeps. The line trigger is obtained from the power supply. The internal trigger is obtained from the trigger amplifier which receives a trigger from either the channel 1 (CH 1) vertical signal or from the normal (NORM) vertical signal after dual trace switching has occurred. This latter trigger is a sample of the composite vertical display.



*6300-40880 MC ON MODEL SA-84W

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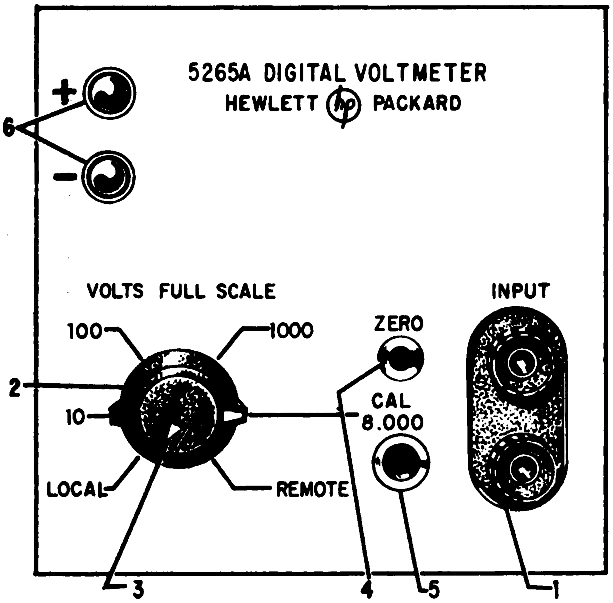
Figure 5-5.—Spectrum analyzer SA-84WA, front panel controls.



1. **Input d-c voltage connector.**
2. **VOLTS FULL SCALE switch.**
3. **LOCAL REMOTE switch.**
4. **Zero adjust control.**
5. **CAL 8.000 control.**
6. **Polarity indicators.**

AQ.6

Figure 5-6.—The 5265A Digital Voltmeter.

The trigger level to either the A or B sweep is adjustable in amplitude and also may be set to either the positive (+) or negative (-) slope of the trigger itself.

The type trigger coupling to each sweep is variable. The coupling may be AC, low-frequency rejection (LF REJ), high-frequency rejection (HF REJ), or DC. In the AC and LF REJ settings the d-c component of the trigger is blocked. In the AC position, frequencies below 30 Hz will be attenuated. In LF REJ, frequency components below 30 KHz will be attenuated. In the HF REJ position, signals below 30 Hz and above 50 KHz will be attenuated.

The A sweep may be triggered for either normal trigger operation (NORM TRIG), as previously mentioned, for free running operation (AUTO TRIG) (no trigger applied), or for single sweep operation (SINGLE SWEEP) in which a single sweep is presented when desired.

SWEEP CAPABILITIES

The A sweep may be operated with sweep time per division from 5 seconds to 0.1 μsec. The B sweep may be operated with sweep time per division from 0.5 seconds to 0.1 μsec. The sweep may be operated such that the entire sweep is controlled by the A sweep controls and a portion of the entire sweep is intensified by the position of the B sweep controls. When operating with a portion of the A sweep intensified and then the B sweep only control (DELAYED SWEEP (B)) is operated, only that portion of the original sweep that was intensified will be displayed. Also available is a magnified operation (X10) in which only the center 1/10 of the original sweep is displayed across the entire scope face when this control is operated.

Intensity modulation of the Z-axis is available. Time markers or similar signals may be externally fed into the Z-axis (Z AXIS INPUT) and these will appear as intensity modulation on the displayed signal.

BASIC APPLICATIONS

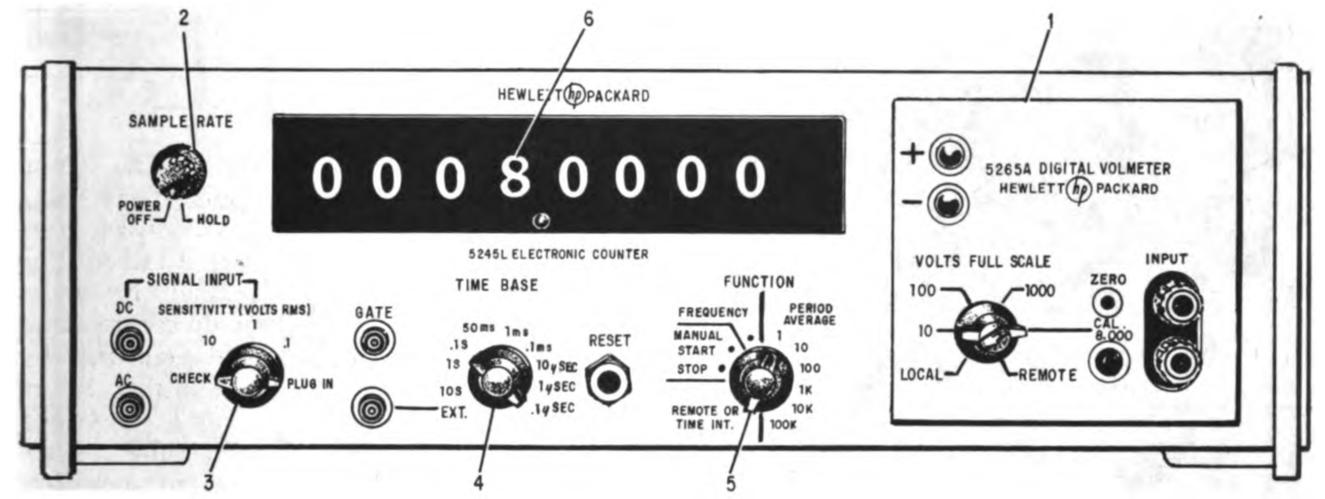
The following applications are a few examples of what may be accomplished with the oscilloscope.

Time Measurement Area

When making time measurements the area between the first and ninth graticule lines should be used because this area is the most linear portion of the sweep. This area is shown in figure 5-9. The position control may be used to set the start of the trace (timing area) on the first graticule line and the TIME/DIV control may be used to end the timing area within the first and ninth graticule lines.

Magnification of Sweep

A portion of a signal display may be magnified by operating the sweep control to magnification (X10). Figure 5-10 shows a signal and an



1. Digital Voltmeter 5265A.
2. SAMPLE RATE.
3. SENSITIVITY switch.
4. TIME BASE switch.
5. FUNCTION switch.
6. Counter display.

AQ.7

Figure 5-7.—Digital Voltmeter 5265A installed in Electronic Counter 5245L.

investigation of the positive portion of the signal is desired. As only the center 1/10 of the sweep will be magnified, the signal should be positioned as shown in figure 5-11; then when the sweep control is positioned to X10 the results shown in figure 5-12 are obtained.

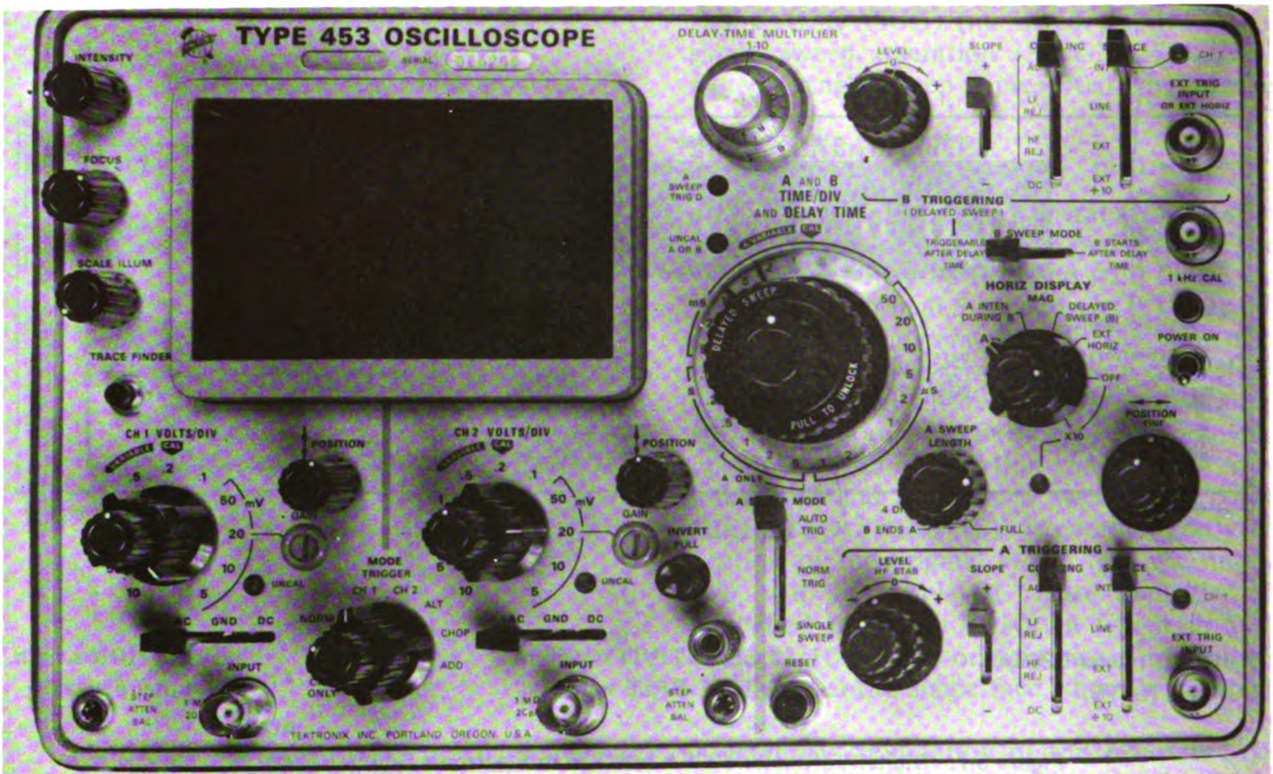
If the time per division in figure 5-11 is 0.5 μsec, the magnified sweep rate is 0.05 μsec per division. This magnified sweep rate must be used for all time measurements.

A Sweep Intensified During B (A inten During B)

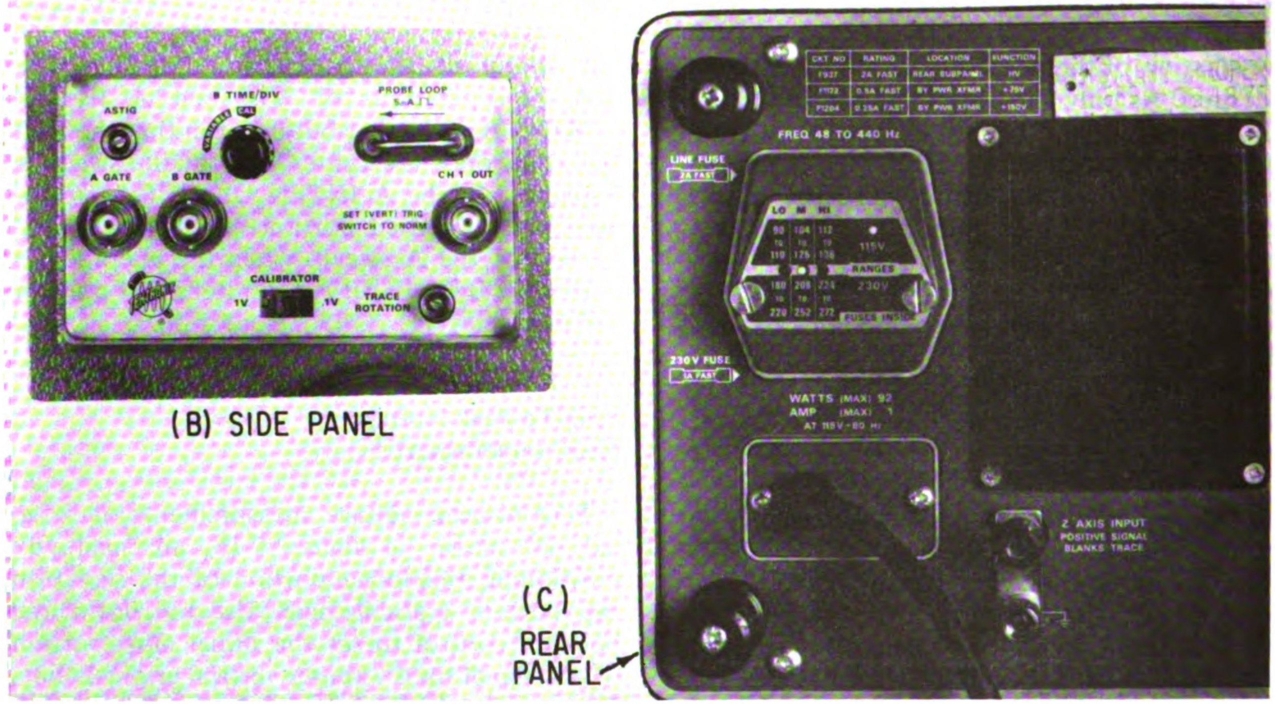
It is possible to cause a portion of a display to be intensified as shown in figure 5-13. This is accomplished by delaying the B sweep. When the B sweep is commenced after the delay, it will appear as an intensified portion of the displayed signal. The length of the intensified portion is determined by the sweep rate of the B sweep control (B TIME/DIV). When B sweep only (DELAYED SWEEP (B)) is operated, the intensified portion of the display in figure 5-13 will appear as shown in figure 5-14. Notice that the operations of X10 and A INTEN DURING B are similar but differ in that the X10 operation only the center 1/10 of the sweep is displayed. In the A INTEN DURING B operation, the intensified portion may be set to any portion of the A sweep. When the operation is shifted to B TIME/DIV, the intensified portion will be displayed.

Peak-To-Peak Voltage Measurements (AC)

Peak-to-peak voltage measurements of a signal, as shown in figure 5-15, are made by positioning the lower portion of the signal on the bottom graticule line. Use the horizontal position control to set the upper most portion of the signal on the center vertical graticule line. The number of divisions, and fractional parts, may now be counted with fair accuracy. The number of divisions are then multiplied by the vertical amplifier control (VOLTS/DIV) setting



(A) FRONT PANEL



(B) SIDE PANEL

(C) REAR PANEL

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Figure 5-8.—Oscilloscope, Type 453. (A) Front panel; (B) side panel, (C) rear panel.

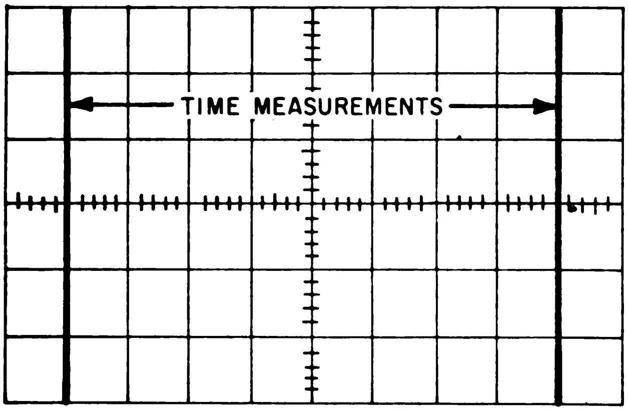

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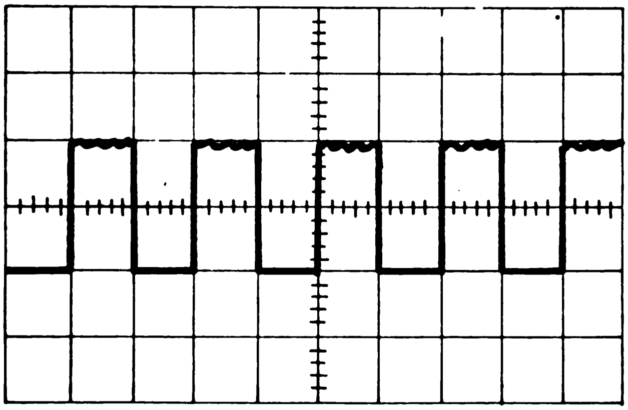
Figure 5-9.—Area to be used for time measurements.

to give the peak-to-peak voltage measurement. NOTE: The VARIABLE volts per division must be in the calibrate (CAL) position for this measurement. This procedure may also be used to make measurement between any two points on a waveform.



AQ.339
Figure 5-10.—Noncentered signal.

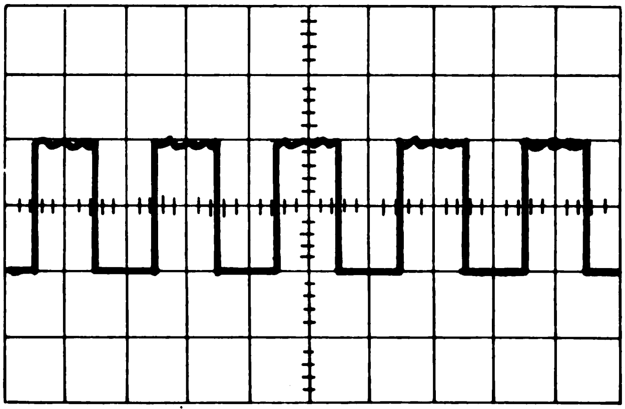


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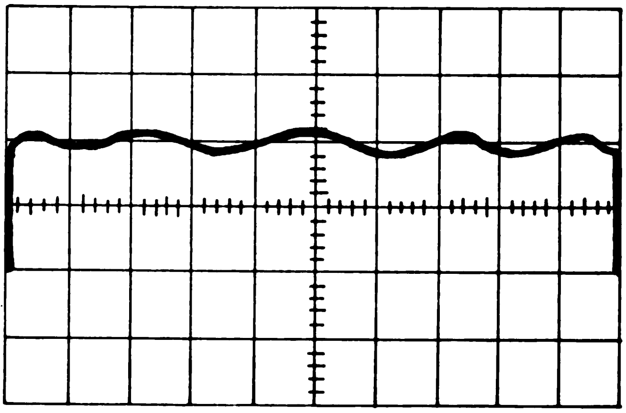
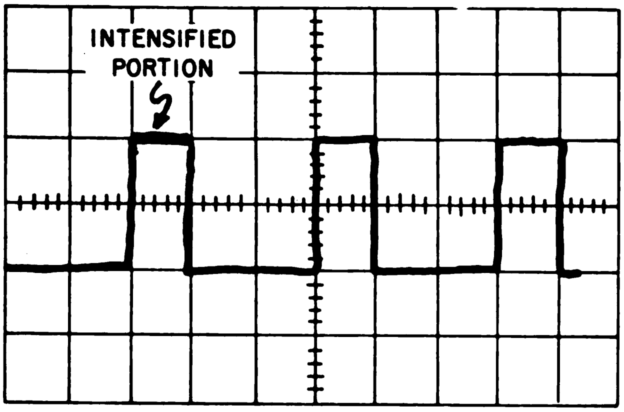
Figure 5-11.—Centered signal.

Instantaneous Voltage Measurement (DC)

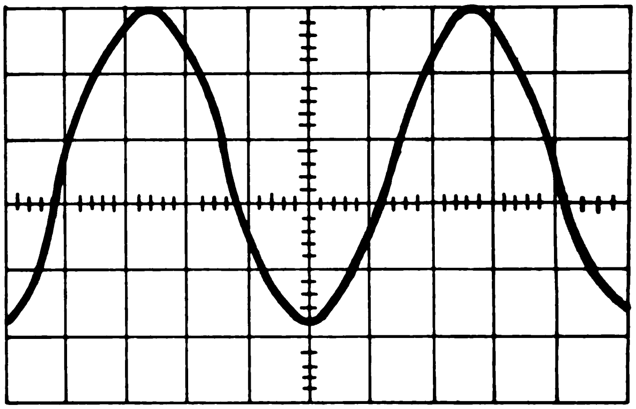
The d-c level at a certain point on the input signal may be measured by coupling the input to the sweep with the AC, GND, DC switch set to



AQ.341
Figure 5-12.—Magnified signal.

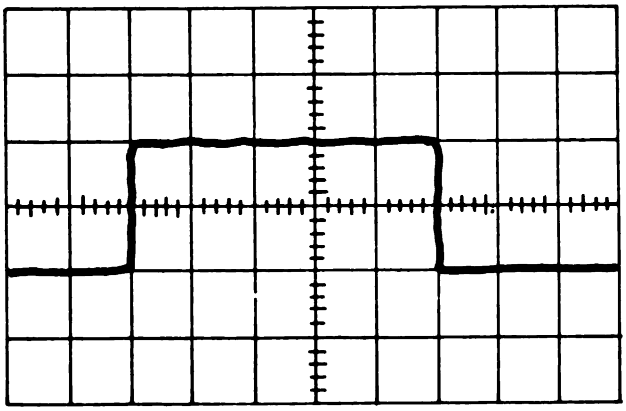


AQ.342
Figure 5-13.—B starts after delay time.

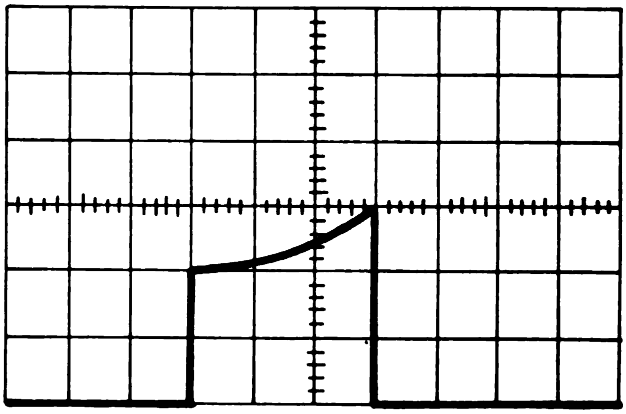


AQ.344
Figure 5-15.—Peak-to-peak voltage measurement (a.c.).

GND position, if voltage is positive with respect to ground. Set the bottom of the signal on the lower graticule. If the voltage is negative, position the trace to the top line of the graticule. The vertical position control should not be moved after this setting. Switch the AC, GND,



AQ.343
Figure 5-14.—B sweep display.



AQ.345
Figure 5-16.—Lower graticule setting.

DC switch to DC. The divisions from the lower graticule to the point on the signal to be measured are multiplied by the VOLTS/DIV setting of vertical amplitude control and the product is the d-c level of the signal. This is shown in figure 5-16, which shows the signal fed in through the GND position and set to the lower graticule. Then, in figure 5-17, the same signal is fed through the DC position. The measurement is made from figure 5-17.

Voltage Comparison Measurements

In some cases it may be desirable to compare a signal voltage to a reference voltage amplitude. A signal of known voltage amplitude is displayed on the sweep and the variable volts per division is used to set this known signal so that the upper and lower portions fall on graticule lines. This is shown in figure 5-18. If the known voltage amplitude of the signal is 24 volts and the VOLTS/DIV switch is set on 5 volts per division then the corrected volts per division is equal to

$$\frac{\text{reference signal (voltage)}}{\text{number of division x VOLTS/DIV setting}}$$

$$= \frac{24}{3 \times 5}$$

$$= 1.6$$

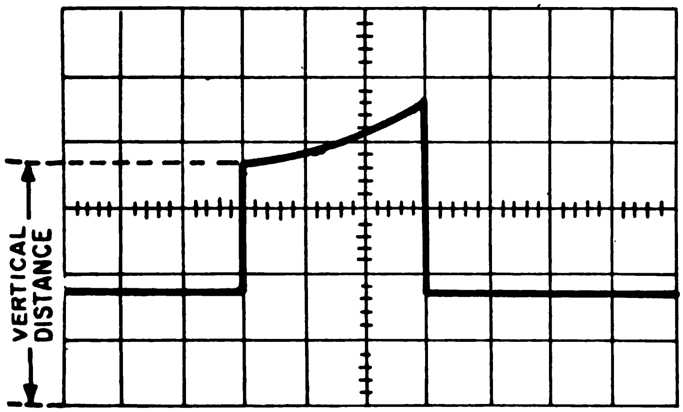


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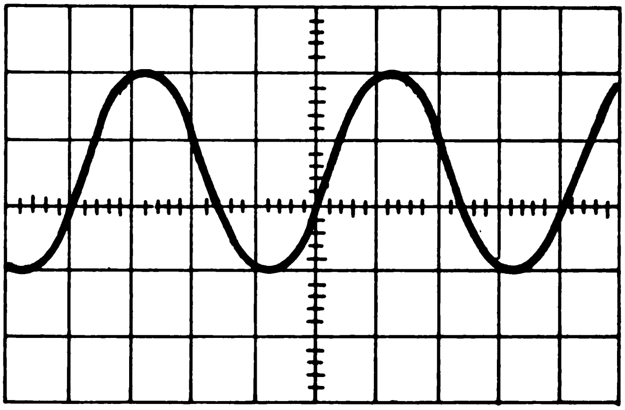
Figure 5-17.—D-c measurement.



AQ.347
Figure 5-18.—Reference signal.

This 1.6 is referred to as the correction factor.

If a signal is now fed into the same channel and appears as shown in figure 5-19, with the VOLTS/DIV set at 2, the signal amplitude is equal to

$$\text{divisions x correction factor x VOLTS/DIV setting}$$

$$= 2 \times 1.6 \times 2$$

$$= 6.4 \text{ volts}$$

Time-Duration Measurements

Time-duration measurements between two points on a signal may be made by setting the TIME/DIV switch so that a display of less than eight divisions between the measurement points is obtained. Set the vertical position control so that the points of measurement fall upon the center graticule. Use the horizontal position control to set the waveform, as shown in figure 5-20, so that the first point of measurement falls

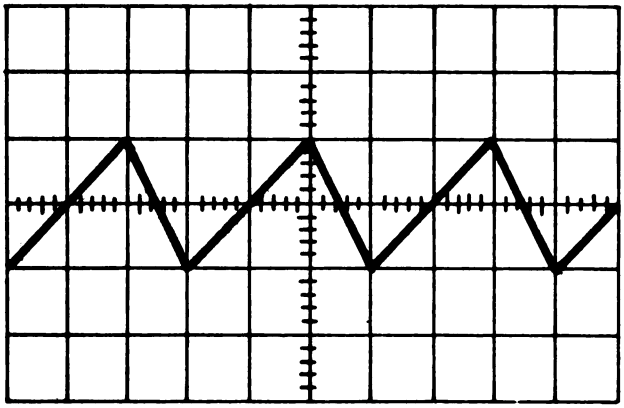


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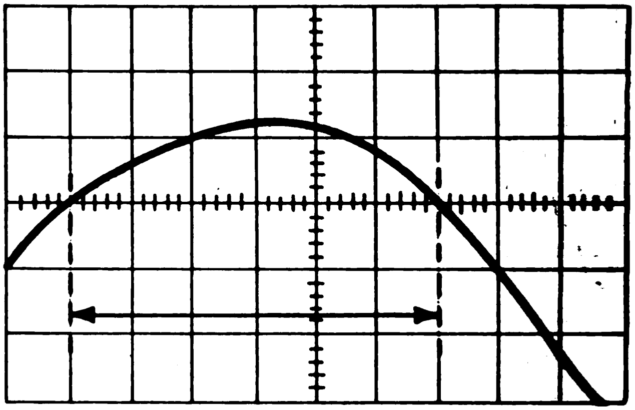
Figure 5-19.—Comparison signal.



AQ.349

Figure 5-20.—Time-duration measurement.

upon the first graticule line. The time between the two points is

TIME/DIV x horizontal divisions

In figure 5-20, if the TIME/DIV is 0.1 msec (millisecond), the time between the points indicated by the dashed lines is

0.1 msec x 6

= 0.6 msec

If sweep magnification is used (X10) then the answer must be divided by 10. That is, if magnification were used to obtain the signal display in figure 5-20, the time duration indicated would be

$$\frac{0.1 \text{ msec} \times 6}{10}$$

= 0.06 msec

Frequency Measurements

Frequency measurements may be made by measuring the time duration of one complete cycle using the procedures previously mentioned and then taking the reciprocal of the time measurement. In figure 5-21, if the TIME/DIV is set at 5 μsec, then the time duration is 5 μsec x 8 divisions which equals 40 μsec. The frequency is equal to

$$\frac{1}{\text{time duration}}$$

$$= \frac{1}{40\,\mu\text{sec}}$$

= .025 megahertz or 25 kHz

Time-Difference Measurements

The time difference between two separate signals may be measured by displaying the signals as shown in figure 5-22. The channel 1 only (CH 1) trigger is used and the reference signal is coupled to channel 1 input and the other signal is coupled to channel 2 input. Either ALT or CHOP position of the MODE switch is used. The difference between the signals is measured in divisions, then this difference is multiplied by the TIME/DIV setting. IF X10 is used the final time difference is divided by 10. If in figure 5-22, the TIME/DIV is 50 μsec and no magnification is used, the time difference between the signals is 50 μsec x 3.5 divisions and equals 175 μsec time difference.

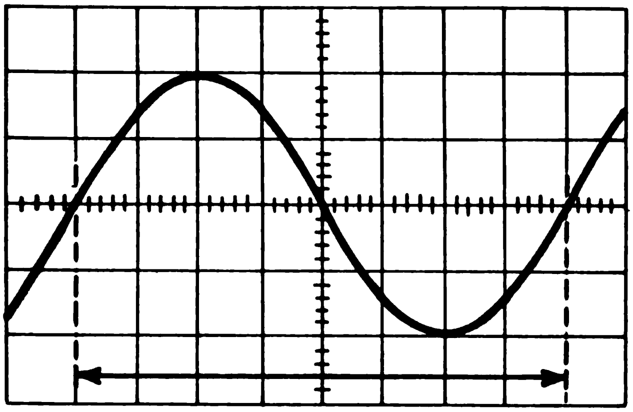


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Figure 5-21.–Frequency measurements.

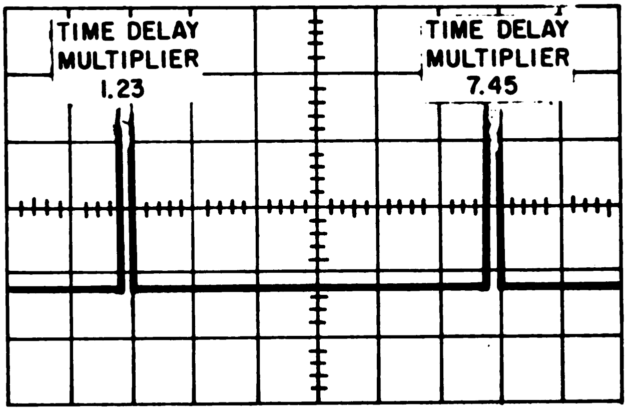

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Figure 5-23.–Time difference.

Delayed Sweep Time Measurements

The delayed sweep mode of operation may be used to make accurate time measurements. The difference in time between two pulses, as shown in figure 5-23, is determined by using A INTEN DURING B. The B TIME/DIV should be set to 1/100 of the A TIME/DIV sweep rate with the B STARTS AFTER DELAY TIME function in use. The delay time multiplier is used to set the intensified portion of the sweep at the peak of the first pulse. The horizontal display is then switched to DELAYED SWEEP (B). The result will be a display as shown in figure 5-24. The

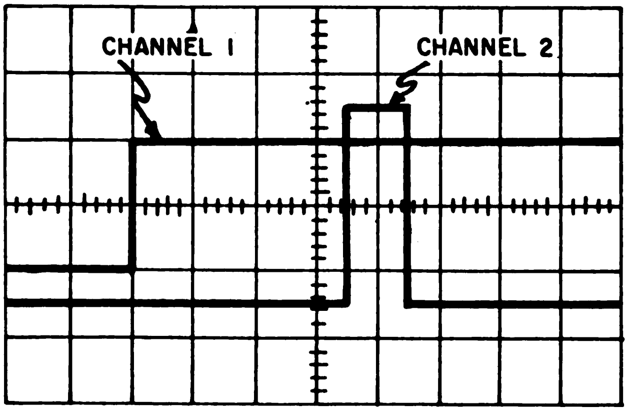

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Figure 5-22.–Time difference measurement.

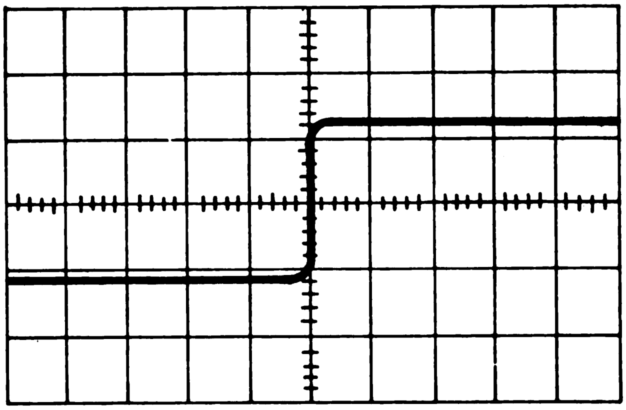

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Figure 5-24.–Magnified pulse time difference.

DELAY-TIME MULTIPLIER is positioned so that the rising portion of the pulse is positioned on the vertical centerline as shown. The reading of the DELAY-TIME MULTIPLIER is noted. The DELAY-TIME MULTIPLIER is then positioned so that the second pulse is positioned as the first pulse was shown. The DELAY-TIME MULTIPLIER reading is again noted. The difference between the two TIME-DELAY MULTIPLIER readings times the A TIME/DIV setting gives the time difference between pulses. In figure 5-23 and figure 5-24 with the A TIME/DIV setting of 0.5 μsec, the difference is

$$(7.45 - 1.23) \times 0.5$$

$$= 3.11\ \mu\text{sec}$$

Delayed Sweep Magnification

When a higher apparent magnification than that produced by the X10 magnification is desired, it may be accomplished by using the A INTEN DURING B and the DELAY-TIME MULTIPLIER. The signal is displayed, as shown in figure 5-25, by using the DELAY-TIME MULTIPLIER to determine when the intensified portion of the sweep starts and using the B TIME/DIV to set the length of the intensified portion of the signal. When the DELAYED SWEEP (B) control is operated, the result will be the display shown in figure 5-26. The apparent magnification of this sweep is found by dividing the A TIME/DIV setting by the B TIME/DIV setting. If the A TIME/DIV is 0.1 msec and the B TIME/DIV setting is 2 μsec, then the apparent magnification is

$$\frac{0.1\ \text{msec}}{2\ \mu\text{sec}}$$

$$= 50$$

Triggered Delayed Sweep Magnification

The difference between this operation and the delayed sweep magnification is that in this operation the B sweep is triggered after the delay from the signal on the B sweep. This will give a more stable B sweep but the B sweep trigger controls must be positioned properly.

Delayed Trigger Generator

When the A INTEN DURING B function is used and the A sweep is triggered internally,

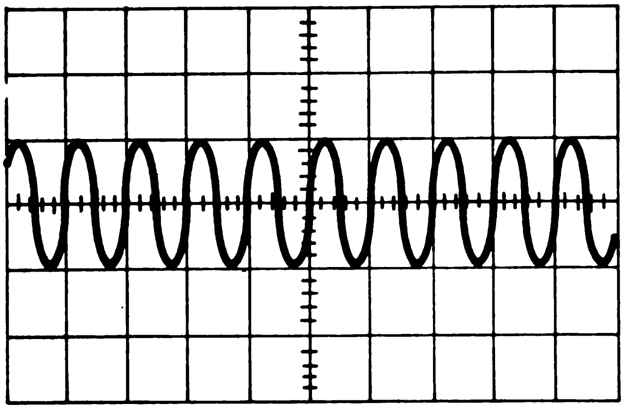

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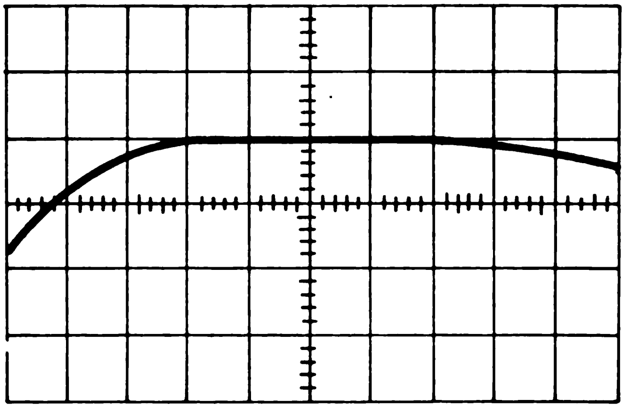
Figure 5-25.—Signal before magnification.



AQ.355
Figure 5-26.—Signal after magnification.

there is available at the B GATE output a triggering signal for use with some external equipment. The trigger available start at the beginning of the intensified portion of the A sweep and its duration is determined by the B TIME/DIV setting. If the external equipment responds to positive going triggers, it will be triggered at the beginning of the intensified portion and if it responds to negative going signals it will be triggered at the completion of the intensified portion.

Trigger Generator

The oscilloscope may be used to trigger external equipment by the A GATE fed to the external signal source. The A trigger LEVEL should be fully clockwise, the A sweep mode to AUTO trigger, and the A TIME/DIV to the desired setting. In this case the external signal source will be triggered by a signal that has a fixed time relationship to the sweep and the signal source output will be displayed as the oscilloscope trace.

Phase Difference Measurements

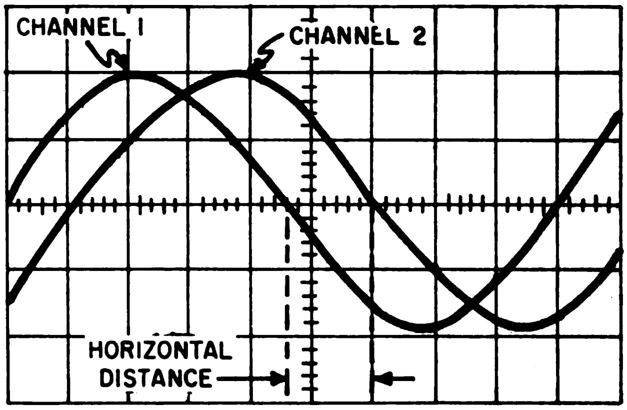
To measure the phase difference between two signals of the same frequency the signals should be displayed as shown in figure 5-27. The signals are fed into channel 1 and 2 respectively with the reference signal preceding the comparison signal in time. Set the reference signal so that one cycle occupies exactly nine divisions horizontally. This is accomplished by use of the A variable control. Since one cycle occupies nine divisions, each division represents 40° per division. The phase difference is the number of divisions times 40°. In figure 5-27 the phase difference is

$$40^\circ \times 1.4 = 56^\circ$$

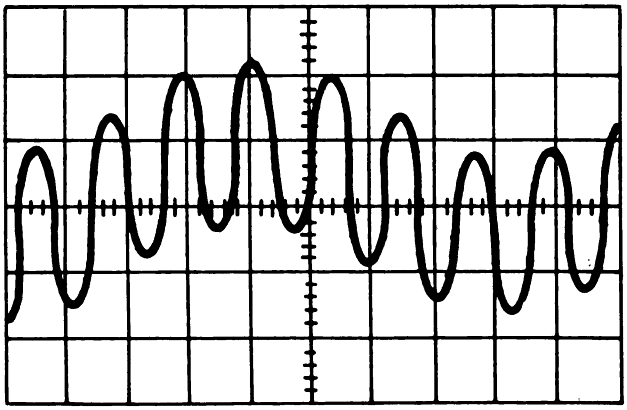
A more accurate measurement may be obtained by using the X10 magnification. In this case the phase difference per division will be $40^\circ \div 10$, or 4°.

Unwanted Signal Rejection

If a displayed signal contains an unwanted component, as shown in figure 5-28, the unwanted component, in this case a line-frquency signal, may be removed by use of the ADD feature of the oscilloscope. With the signal in figure 5-28 coupled to channel 1, couple a line frequency component to channel 2. Invert channel 2 and use the ADD position. The signal on channel 2 will add to the signal on channel 1 and



AQ.356
Figure 5-27.—Phase difference measurements.



AQ.357
Figure 5-28.—Line-frequency component present.

the result will be as shown in figure 5-29. This is due to the line-frequency components being opposite in polarity and when added they cancel each other.

PHASE-ANGLE VOLTMETERS

In a complex waveform where there are a fundamental frequency and harmonics, there is a problem in measuring phase shift. In many applications, personnel are interested in the phase relationship of the fundamental frequency, regardless of the phase relationship of any harmonics which may exist. In figure 5-30, waveform A represents the input waveform to a circuit. Waveform D represents the complex waveform out of the circuit. Waveform D is composed of B, which is the fundamental frequency, and C, which is the third harmonic of the fundamental. If the input were compared with the output by measuring either the phase shift between the maximum points or the zero points, some amount of phase shift would be measured. If only the fundamental portion of waveform D were compared with the input, the fundamental portion of the output would be seen in phase with the input frequency. One of the things that a phase-measuring device must be able to do is measure the phase difference between two discrete frequencies, regardless of the phase and amplitude of the other waveform components.

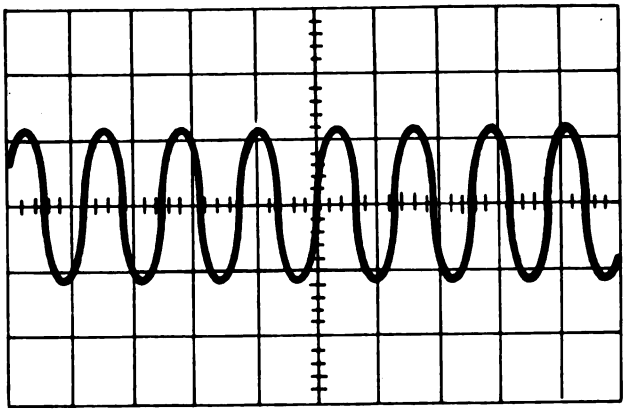


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Figure 5-29.—Line-frequency component canceled.

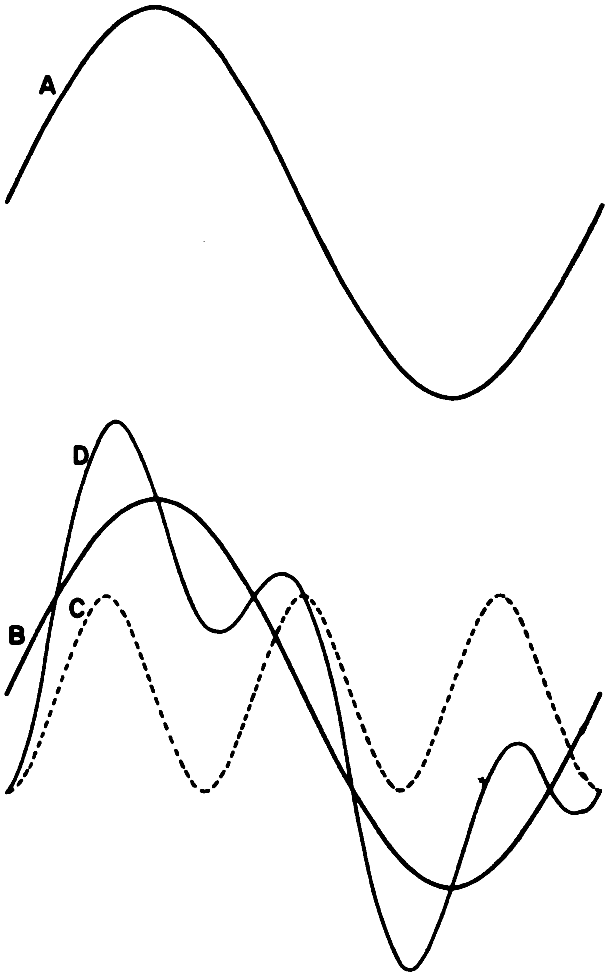

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Figure 5-30.—Input and output waveforms, phase angle voltmeters.

Most phase-angle voltmeters in use by the Navy today are single frequency devices. They are supplied with filters which are set for a single frequency, and the meter cannot be used to measure phase differences of other frequencies.

The filters in the meters supplied to the Navy are set for 400 Hz.

The two phase-angle voltmeters most commonly used by the Navy are the North Atlantic Model 202BR and the Dytronics Model 240. These meters are capable of measuring 400 Hz phase shifts.

NORTH ATLANTIC 202BR PHASE-ANGLE VOLTMETER

The North Atlantic 202BR requires that the function switch be in a position where the degree dial can be set to give a zero reading on the meter. This is a quadrature point, and this zero reading can occur when the signal is either 90° or 270° from the actual amount of phase shift. As an example, where there are two signals and the signal connected to the signal input leads the one connected to the reference input by 100°, the meter can be zeroed by setting the degree dial at 10° with the function switch at either 0° or 180°. If this is the quadrature point, it means the correct quadrant must be either 90° or 270°. The meter is designed so that when the function switch is rotated, the correct quadrant will make the meter deflect to the right of center. and the other quadrant will drive the needle to the left. In this example, when the function switch is on 90°, the needle will deflect to the right whether the meter is zeroed on 0° or 180°. Once the quadrant where the needle will deflect to the right is found, the number of degrees on the function switch can be added to the number of degrees on the degree dial. In this case, it would be 90° from the reading on the function switch plus 10° from the reading on the degree dial, for a total of 100°; this is the number of degrees the signal is leading the reference.

It is important to keep in mind the fact that the voltmeter is designed to indicate the number of degrees by which the signal input leads the reference input. The foregoing problem—the signal input leading the reference by 100°—could have been stated showing the signal input lagging the reference by 260°. To change from a lagging to a leading phase shift, subtract from 360° the number of degrees the phase shift lags.

If manuals or alinement procedures describe phase shifts as lagging, and a technician is working with the North Atlantic 202BR phase-angle voltmeter, the phase shift should be converted to a leading angle. In most cases, this is the simplest method of dealing with the problem. In some instances, however, it may be easier to reverse the inputs. For example, if an alinement procedure called for a signal input to lag the reference input by 30°, and the reference were connected to the reference input and the signal to the signal input, the voltmeter would measure 330° because the instrument is designed to indicate leading phase. If the reference were connected to the signal input and the signal to the reference input, there would be an indication of 30°. If a technician were completely familiar with the equipment being tested and with the voltmeter, he could interpret this as the correct amount of phase shift. The one difficulty with this method is that the input connections are not the same for every measurement, and it is easy to reverse the inputs when they should not be reversed.

DYTRONICS MODEL 240 PHASE-ANGLE VOLTMETER

The Dytronics Model 240 has a two-position switch labeled "in-phase" and "quadrature". When this switch is in quadrature, the quadrant selector is actually 90° from whatever position it indicates on the switch. This eliminates the need of switching quadrants once the meter is nulled, because whatever is read off the quadrant selector has already been shifted 90°. The method used to find zero voltage is the same as that used with the North Atlantic meter; that is, the setting of the quadrant selector must allow the phase-angle potentiometer to zero the meter. Since there are two zero points, the ambiguity is eliminated by turning the phase-angle potentiometer once the zero point is reached. If the meter needle travels in the same direction in which the potentiometer is turned, the correct zero point is obtained. If it travels in the opposite direction, the quadrant selector must be moved until the other zero point is found. The number of degrees indicated on the quadrant selector added to the number of degrees on the phase-angle potentiometer dial gives the number of degrees the signal is lagging the reference input.

On one voltmeter, the quadrant in which the meter is nulled is part of the readout; and on the other meter, the quadrant is the point at which the meter needle deflects to the right for a readout. Also, one voltmeter shows the number of degrees the signal input lags the reference, while the other shows the number of degrees the signal input leads the reference. These variations cause confusion if the technician is unaware of them.

TIME-DOMAIN REFLECTOMETRY

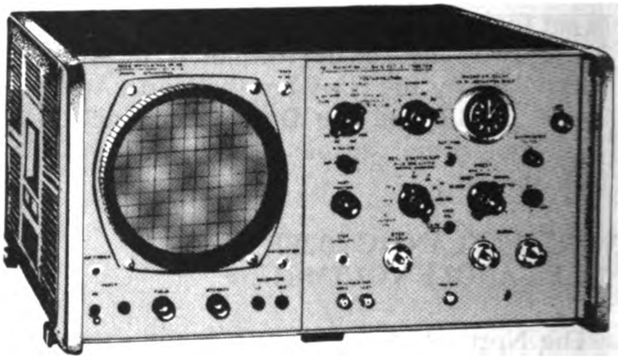
Time-domain reflectometry (TDR) is an application of a pulse reflection measurement technique. It is not new, as it has been used for many years to locate discontinuities in high voltage transmission lines, and today TDR can be used in both wideband and narrow-band systems to indicate the distance to the fault as well as an indication of its nature.

The TDR can be compared to a closed-loop one-dimensional radar, where the transmitted signal is a very fast step function and the reflected signals are monitored on the oscilloscope screen. The faster the step, the greater the distance resolution, because distance is related to time in this technique. The amplitude of the reflected step is directly related to the impedance so that any change from the 50-ohm output of the Model 1415A Time Domain Reflectometer can be recognized and measured.

Figure 5-31 shows the Model 1415A Time Domain Reflectometer unit plugged into the HP 140A sampling oscilloscope.

TDR BASICS

The TDR analysis consists of the insertion of a step or pulse of energy into a system and the subsequent observation, at the point of insertion, of the energy reflected by the system. Several arrangements are possible, but the following procedure is used with the newer, specialized reflectometers. (See fig. 5-32). A fast (or incident) step is developed in the pulse generator. This step then passes through a TEE connector and is sent into the system under test. The sampling oscilloscope is attached to the TEE connector and the incident step, along with the reflected waveform, is displayed on the CRT. Analysis of the magnitude, duration, and shape of the reflected waveform will determine the type of impedance variation in the system under test.

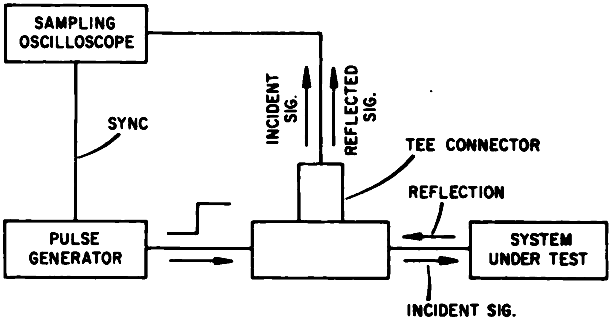


AQ.9

Figure 5-31.—Model 1415A time domain reflectometer installed in Model 140A oscilloscope.

Sampling Technique

Since the speed needed for TDR exceeds the response of the oscilloscope, a technique of sampling is employed. To prevent a continuous monitoring of the reflected signals, the Model 1415A Time Domain Reflectometer takes a series of 4,000 separate samples of the reflections every 20 milliseconds. Every sample is



AT.407

Figure 5-32.—Typical time domain reflectometer.

displayed as a single dot on the face of the oscilloscope, but when 4,000 dots are displayed on a 10-cm display area, they appear as a continuous line or trace. Each successive sample in a series is delayed with respect to the incident pulse by a predetermined time. Also, the entire series of 4,000 samples may be delayed so that reflections from a small area located a great distance down the line may be magnified for better resolution.

Resistive Loads

If a pure resistive load is placed on the output of the reflectometer and a step signal applied, a signal whose amplitude is a function of the resistance (fig. 5-33) is observed on the CRT. If the line is terminated in its characteristic impedance (Z_0) as shown in figure 5-33, there will be no reflected signal and the signal observed on the CRT will remain flat; but if the impedance (R_L) at the termination is greater or less than Z_0, then reflections will exist. The amplitude of the reflected signal is proportional to the value of R_L. If R_L is greater than Z_0, the reflected signal will be in phase with the incident signal; and when applied to the CRT, it will add to the incident signal. If R_L is less than Z_0, the reflection will be 180° out of phase with the incident signal; and when applied to the CRT will subtract from the incident signal. The dotted lines in figure 5-33 represent the composite signal (incident plus the reflected) observed on the oscilloscope. The time from the start of the step to the reflection represents twice the distance to the discontinuity. This is the time it takes the step to travel down the line to the discontinuity and return.

It is good practice to separate the system under test from the TDR unit's tee connector by at least 8 inches of 50-ohm cable. Such a separation moves the reflections away from the leading edge of the step, so that overshoot and ringing are not superimposed on the observed signal.

Reactive Loads

The waveform of reactive loads (fig. 5-34) depends upon the time constant formed by the load and the 50-ohm source. The series RL network in (A) of figure 5-34 appears as an open the instant the step voltage reaches it because the inductor L offers maximum impedance to the change in current caused by the step voltage. Therefore, the reflected signal is in phase with

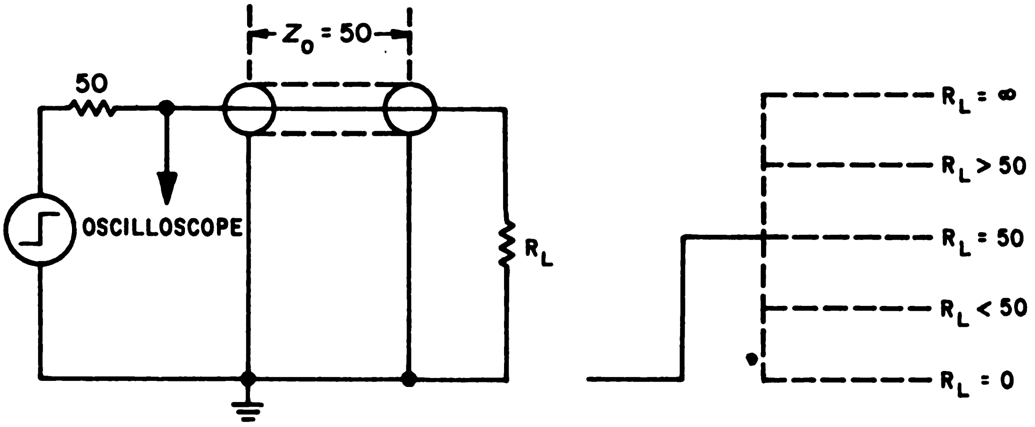
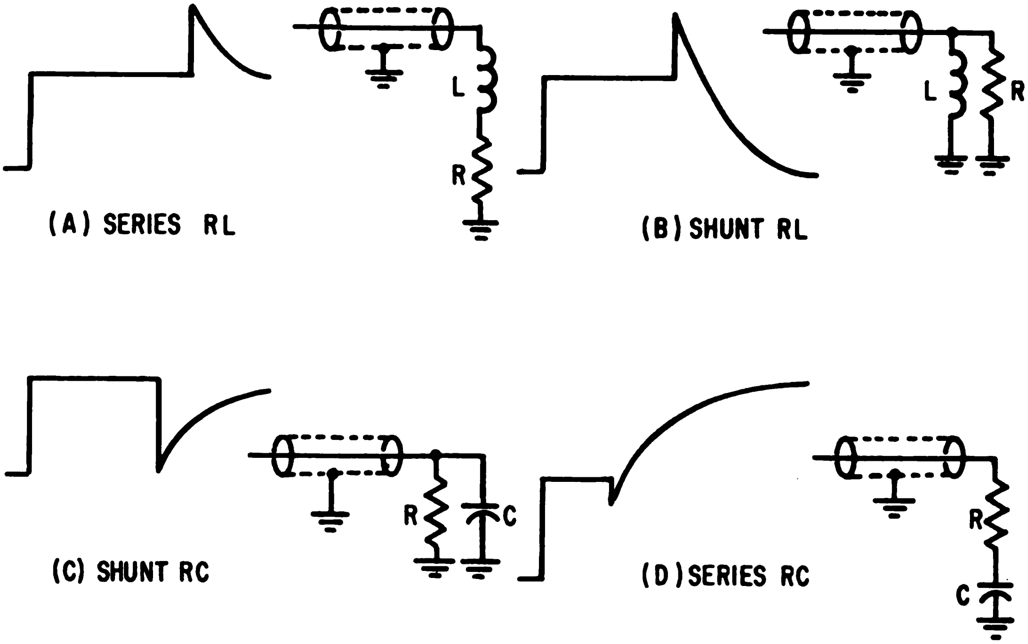


Figure 5-33.—Step signal-height variations resulting from different resistive loads.



AT.409
Figure 5-34.—TDR reactive load characteristics (time constant = 1).

the step voltage and is additive. This explains the sharp rise in voltage. However, as soon as the inductor saturates, the only opposition to current is resistor R; and since L saturates at a nonlinear rate, the voltage drops at a nonlinear rate from the peak of the spike to the same level as the flat portion of the step voltage. At this time the only load seen by the line is the 50-ohm resistor which is equal to the characteristic impedance of the line, and the reflections cease until the next step appears at the termination and the cycle repeats itself.

The waveshape in figure 5-34 (B) can be understood by remembering that L appears as an open to the fast rising step voltage the instant it is felt at the termination; but as the inductor saturates, it offers less and less opposition to current until it is completely saturated (0 ohm). Since the inductor is parallel to R, the termination is a short and the reflected wave is 180° out of phase with the incident wave. Since L saturates at a nonlinear rate, the voltage declines at a nonlinear rate. A similar analysis can be made of the transmission lines with the RC terminations shown in (C) and (D) of figure 5-34.

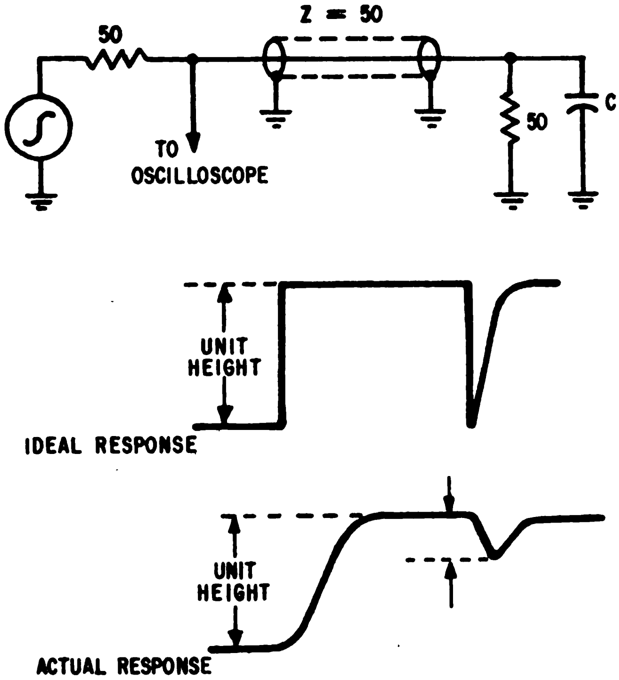
The analysis just made of the different types of discontinuities explains the usefulness of TDR. Not only can a discontinuity be determined, but through proper analysis you can determine whether it is resistive, inductive, or capacitive, and whether it is in series or parallel with the load.

TDR IN PRACTICE

TDR discontinuities are clearly separated in time on the CRT; it is easy to see the mismatch caused by a connector even if a bad discontinuity is present elsewhere in the system. By using the aforementioned analysis, it is possible to establish which connector is troublesome and in what way. Once it is determined that a discontinuity appears in a waveform, it is simple to locate it in the system. A timesaving way of doing this is to calibrate the system so that 1 centimeter on the horizontal axis is the equivalent of a certain number of feet for the transmission system under test. The limiting factor is the system rise time, and any closely spaced discontinuities will appear as a single discontinuity.

The finite rise time also limits the size of the distinguishable reactive impedance response. For example, a small shunt capacitance in a 50-ohm system will cause the waveform to depart from the ideal response (fig. 5-35).

The maximum observable line length is a function of the repetition rate chosen. This rate determines the duration of the pulse after its rise. For example, a 200-KHz repetition rate permits the use of TDR devices with up to 1,000 feet of air dielectric cable or 670 feet of polyethelene dielectric coaxial cable. The speed at which a wave travels through a transmission system is determined by the system's velocity constant; thus a wave travels faster through air than through polyethylene. This explains the difference in maximum lengths of coaxial cable that can be checked using a particular repetition rate on the TDR–the longer the cable, the lower must be the repetition rate.



AT.410

Figure 5-35.–Small shunt capacitance in system degrades ideal response.

RANGE AND RESOLUTION

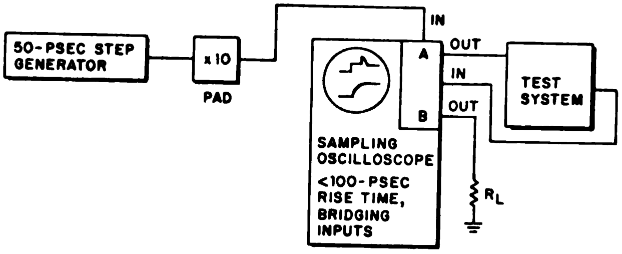
Assuming that the total impedance (Z_0) equals 50 ohms, a resistance between 0.025 ohm and 100 K ohms may be measured. Because the height of the reflection is directly proportional to the resistance encountered, the resistance may be determined by the use of a pre-calculated transparent overlay.

One common use of TDR is in analyzing a coaxial cable. The amount of impedance variation that can be detected in a long section of cable is a function of the flatness of the top of the incident step. If this step is flat within ± one-half percent, impedance variation of one-half ohm along the cable can be detected, corresponding to a one percent check on cable impedance. Thus, irregularities in cable makeup resulting from variations in the braiding process or tightness of the insulating jacket show up clearly.

TDR TECHNIQUES

For applications where the ouput of a test system is of interest, a dual-channel sampling oscilloscope can be used in a TDR configuration to display both the input and transmission characteristics of the system (fig. 5-36).

The step generator is connected to the sampled channel and an accurate 50-ohm termination is connected to the output for the initial calibration. This termination can be a one percent film type load resistor with short lead lengths. Prior to removal of the 50-ohm termination and connection of the test system, the vertical gain of the oscilloscope is adjusted to give a 10-centimeter step.

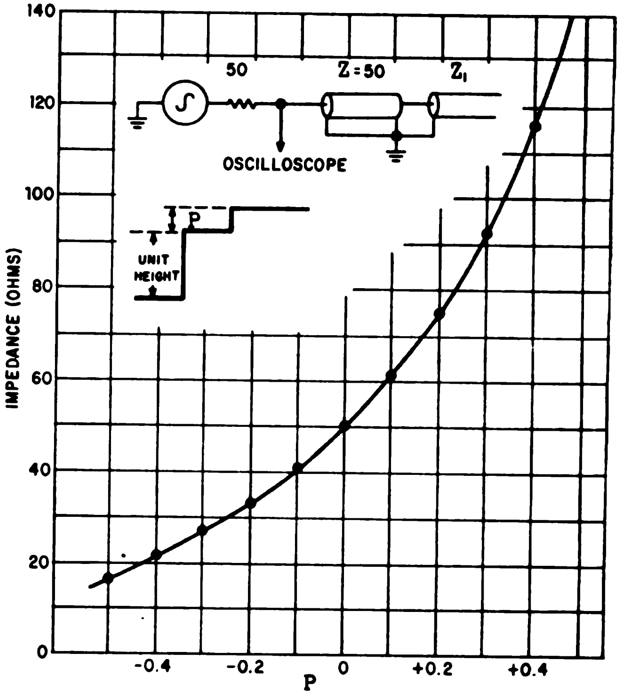


AT.411

Figure 5-36.—Dual-channel oscilloscope analysis of reflection and transmission characteristics.

The magnitude and location of reflections can be viewed more closely by selection of an appropriate time scale and vertical magnification. Calibration of the horizontal reflection allows rapid physical location of points of interest. Calibration of the vertical axis in terms of the reflection coefficient (the change in amplitude of the flat portion of the incident waveform caused by the reflected signal; for example, p of figure 5-37) allows direct interpretation of cable impedance at the discontinuity.

With the sampling oscilloscope calibrated, cable impedance can be determined from the height of the reflected step. The graph shown in figure 5-37 may be used to translate step heights into impedance.



AT.412

Figure 5-37.—Curve for the conversion of normalized reflected pulse height into system impedance.

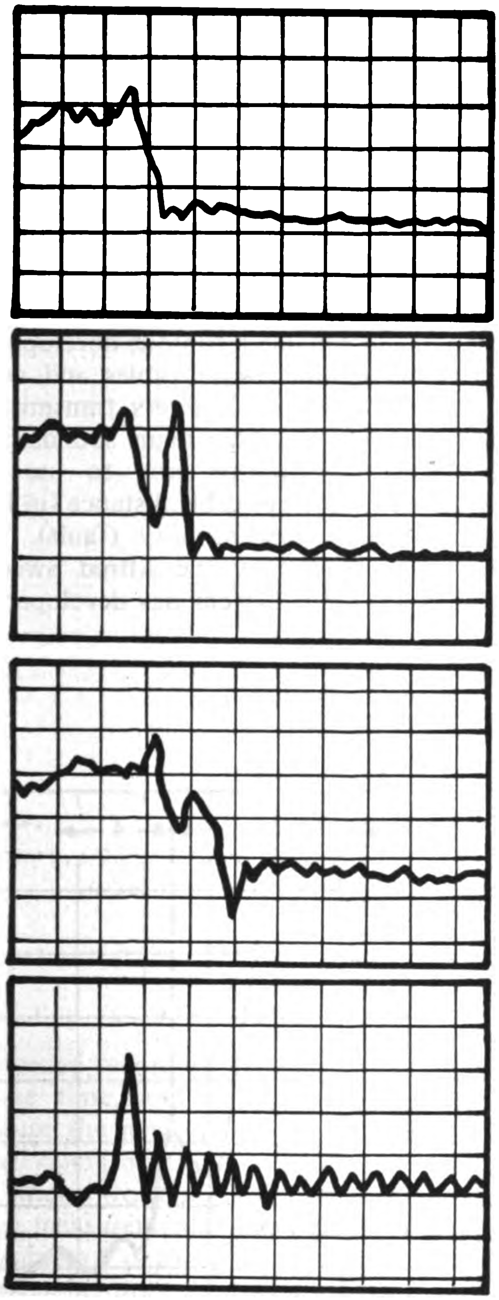
ANALYZING TERMINATIONS

Departure from 50 ohms in a termination or cable connector can cause large reflections in a pulse system or a large voltage standing wave ratio (VSWR) in a system that carries primarily sinusoidal signals. Because of human errors in the assembly process, even the best connectors unfortunately cause reflections or a varying VSWR. Expensive connectors, therefore, do not insure freedom from unwanted reflections, but TDR helps locate unacceptable connectors by rapidly showing where the mismatches are, how bad they are, if they are resistive, capcitive, or inductive, and whether series or shunt.

Figure 5-38 shows a step being propagated from a section of RG9A/U into a load. The connector on the load and the cable are the General Radio Type 874. Four different cases are shown with varying loads, thus illustrating how the connection and the load can be analyzed by use of the TDR. With different connectors and loads, the small mismatches (discontinuities) take on different impedance characteristics and the reflected signals change. This change is also reflected in the wave shape viewed on the oscilloscope. A comparison between these signals and those of a normal system can be made by using an overlay showing the pattern of a normal system.

Cable Impedance

The most convenient method of reflectometer use in making precise measurements of cable impedance is to connect a section of air dielec-



AT.413

Figure 5-38.—Waveforms resulting from the use of different loads. Horizontal scale 0.4 μsec/cm; vertical scale 0.5 percent/cm.

tric line with precisely determined impedance between the test cable and the TDR unit. The step height through the air dielectric line section sets the 50-ohm level. Variations from this level in the test cable are noted, and the impedance of the cable is calculated (fig. 5-39). In this test, the impedance level of the test line is

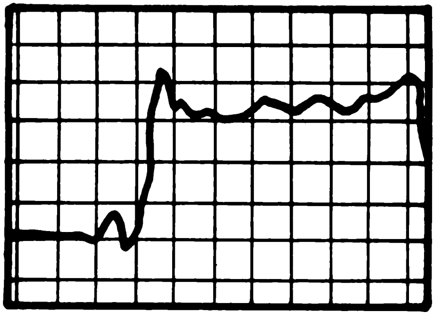
$$Z_0 = 50 \frac{1 + p}{1 - p}$$

where p is the reflection coefficient of the reflected mismatch. The change in amplitude shows p to be +0.03, so

$$Z_0 = 50 \frac{1.03}{0.97} = 53 \text{ ohms}$$

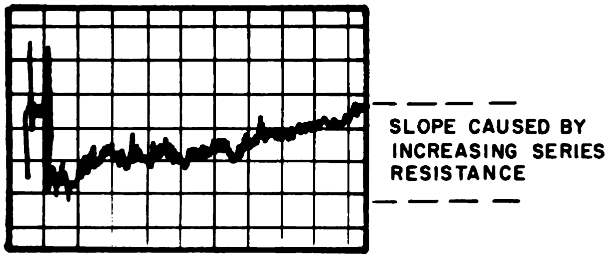
The impedance of a long section of coaxial cable would be exactly Z_0 if there were no line losses. However, most cables have a small series loss and a negligible shunt loss. This series resistance adds to Z_0, causing the impedance level, as observed at one end of a cable, to increase as longer sections of cable are added. The slope on the step height that results from the increasing impedance is evident in figure 5-40.

Other applications in which the TDR method of analysis can be used effectively are the component characteristic analysis and antenna



AT.414

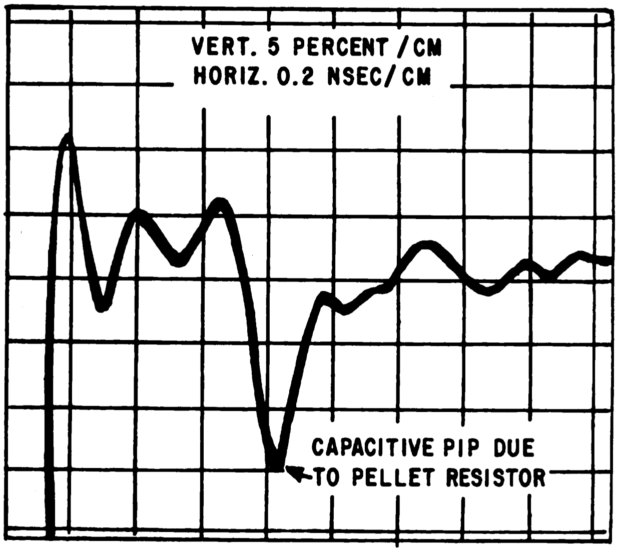
Figure 5-39.—Oscillograph of step from air dielectric line into test cable.



AT.415

Figure 5-40.—Trace of cable shows construction irregularities and increasing series resistance.

analysis. The components can be placed in an appropriate jig and the TDR method used to determine their shunt capacity and series inductance (fig. 5-41).



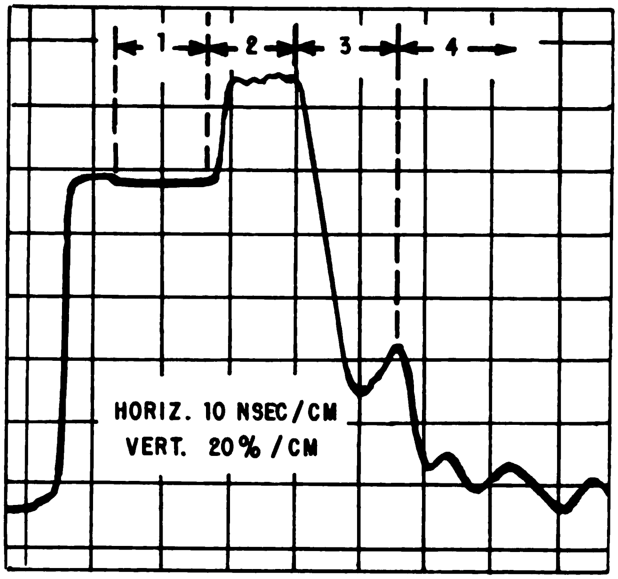
AT.416

Figure 5-41.—Resistor checked for shunt capacity with special jig.

Investigation of antennas will reveal that the TDR pattern is not simple, but instead presents a complex reactive profile (fig. 5-42). Once the proper profile for a particular antenna is determined, any improper construction details can be detected and the proper corrective action ascertained.

FREQUENCY-DOMAIN REFLECTOMETRY

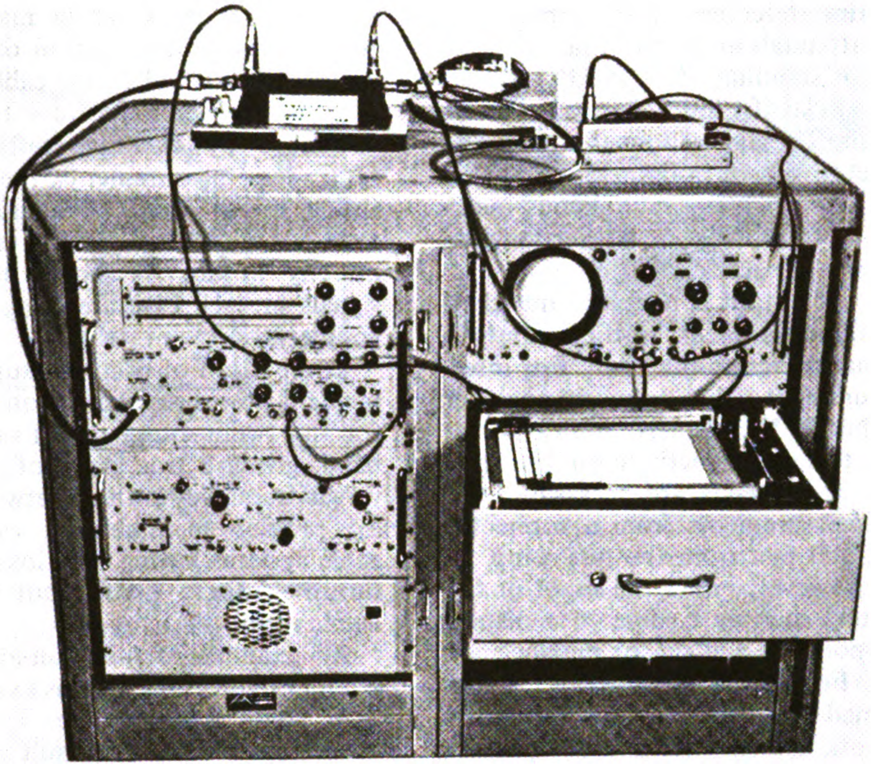
Frequency-domain reflectometry (FDR) is a fast, simple, and reliable technique developed to locate defects in microwave cables and waveguide systems connecting receivers, transmitters, and antennas. Although the name sounds complicated, the technique is easy to use and permits direct readout of cable distance (in feet) to the impedance discontinuity (fault). This capability is provided by the Alfred Sweeper Cart (fig. 5-43). This system has developed an



1. 50-ohm feedline.
2. 75-ohm antenna.
3. Short at end of antenna.
4. Rereflections.

AT.417

Figure 5-42.—Scope trace of antenna reactive profile.



AT.418

Figure 5-43.–FDR cable testing system.

impressive record of reliability, greatly reduced service time, and improved service standards. Because the new system checks cables at their actual operating frequencies, discontinuities outside those frequencies will not affect the test. When measurements indicate a fault, its location (in terms of distance in feet from the point of test) can be precisely determined. Repairs, therefore, can be made quickly and efficiently.

FDR VERSUS TDR

Until now, cables have been tested primarily by means of time-domain reflectometry, a system which has several severe limitations. For example, TDR makes measurements covering a spectrum determined by its pulse characteristics and therefore identifies all discontinuities or parameter changes including those outside the operating frequency range which do not affect system operation. With FDR, however, the analysis is made at the actual operating frequency band of the microwave system, thereby assuring proper system performance at the operating frequencies.

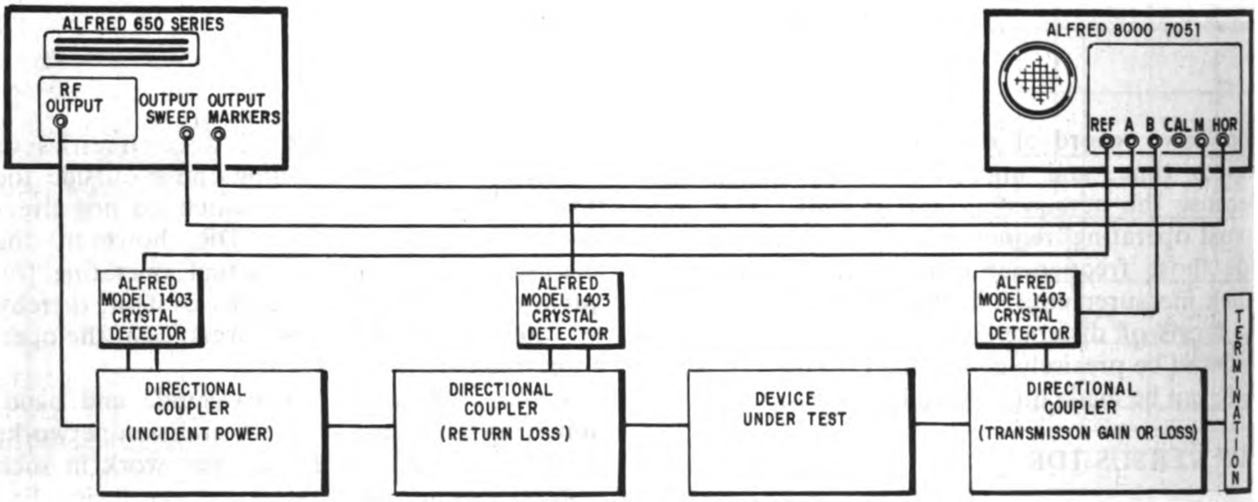
While FDR works in waveguide and band-limited systems including transmission networks that contain filters, TDR cannot work in such systems because it requires a transmission line that passes the whole spectrum from the fundamental frequency (2 MHz to 5 MHz) to the highest harmonic (15 GHz). Waveguides which act as high-pass filters cannot transmit TDR pulses. Similarly, TDR cannot see through low-pass or bandpass filters because these eliminate the low-frequency harmonics.

FDR identifies defective systems by using insertion-loss (attenuation in the line) and return-loss (voltage standing wave ratio (VSWR)) measurements to classify the system as good or in need of repair. These measurements are made with the test setup shown in figure 5-44. Such a test configuration provides simultaneous measurement of both return loss and insertion loss (or gain) of passive (or active) devices.

If the input and output connectors are accessible, an insertion-loss check verifies input-to-output performance across the band. For insertion-loss measurement, the network analyzer (using its B and REF channels) indicates the ratio of output to input directly in db. For tests of long cables whose ends are accessible, the system allows measurements from a connector end as far as 2,000 feet from the test setup. In some systems, however, either the input or the output connector, such as a cable to a distant superstructure point in a plane or missile, may be inaccessible. For such systems, a return-loss measurement made on the accessible connector will provide a total system check. In equipments that utilize duplexers or in high-gain systems in which an active device isolates input and output, a return-loss check can be made from each end. Another useful application of return-loss measurement occurs when the cable feeds the output of a high-power microwave tube which can be destroyed by excessive reflected energy. For return-loss measurements, the network analyzer (using the A and REF channels) indicates the ratio of reflected power to incident power directly in db. As shown in figure 5-44, the signals in each case are sampled by directional couplers.

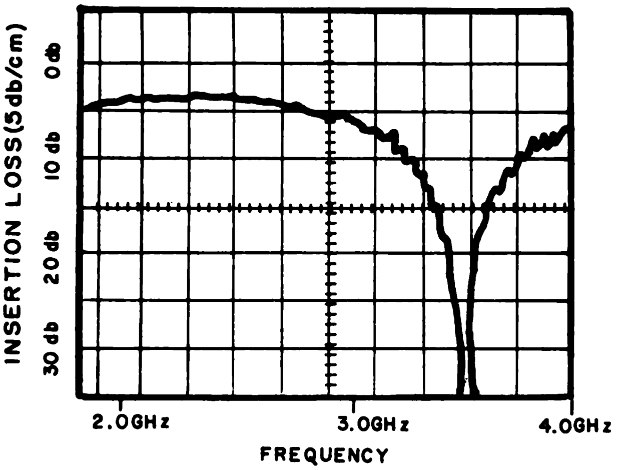
Comparison of each measured signal with the incident power supplies automatic compensation for any swept-source power variations across the band, giving a true graph of performance in db versus frequency on the network analyzer CRT. To provide measurement capability for long cable systems having high losses, the instrument furnishes direct db readout over a 60-db dynamic range.

An example of insertion-loss measurement is given in figure 5-45. In this example a loss of less than 10 db is acceptable. The cable, however, needs repair because a fault which produces an


ALFRED 650 SERIES
RF OUTPUT
OUTPUT SWEEP
OUTPUT MARKERS
ALFRED 8000 7051
REF
A
B
CAL M
HOR
ALFRED MODEL 1403 CRYSTAL DETECTOR
ALFRED MODEL 1403 CRYSTAL DETECTOR
ALFRED MODEL 1403 CRYSTAL DETECTOR
DIRECTIONAL COUPLER (INCIDENT POWER)
DIRECTIONAL COUPLER (RETURN LOSS)
DEVICE UNDER TEST
DIRECTIONAL COUPLER (TRANSMISSON GAIN OR LOSS)
TERMINATION

AT.419

Figure 5-44.—Test setup for VSWR and insertion performance.



AT.420

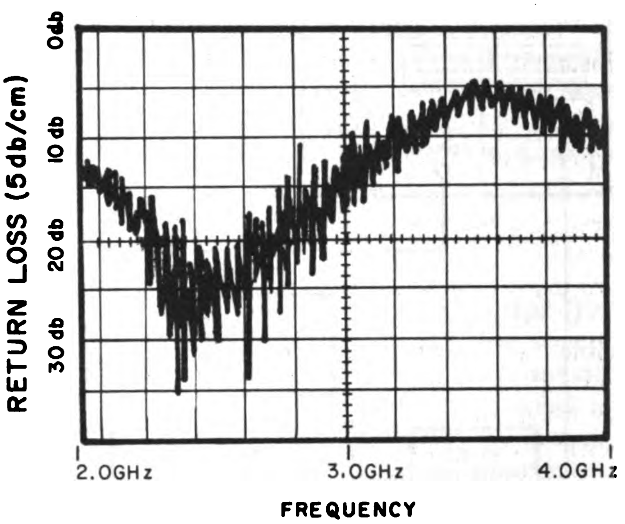
Figure 5-45.—Insertion-loss display.

insertion loss greater than 35 db at a frequency of 3.56 GHz is present.

An example of a return-loss measurement for the same cable is shown in figure 5-46. Here, a loss of 11 db, which corresponds to a VSWR of less than 1.8, is acceptable. At 3.56 GHz, then, the return loss is equal to 5 db, which corresponds to a VSWR of 3.6.

The dual-channel network analyzer permits display of both measurements simultaneously when the complete test setup shown in figure 5-44 is used.

For cable-length and fault-location measurements, a waveguide or coaxial tee is incorporated in the test setup (fig. 5-47); the system is calibrated with the calibration cable, and then the cable under test is connected to the tee. (The calibration referred to in this paragraph is an operator adjustment, not a calibration to be performed by a metrology activity.) The resultant CRT display on the network analyzer consists of a stationary pattern containing a series of "half-dome ripples." A count of the total number of these ripples indicates the number of feet from the cable end to the fault, as illustrated in figure 5-48. The FDR display is from the cable system which produced the



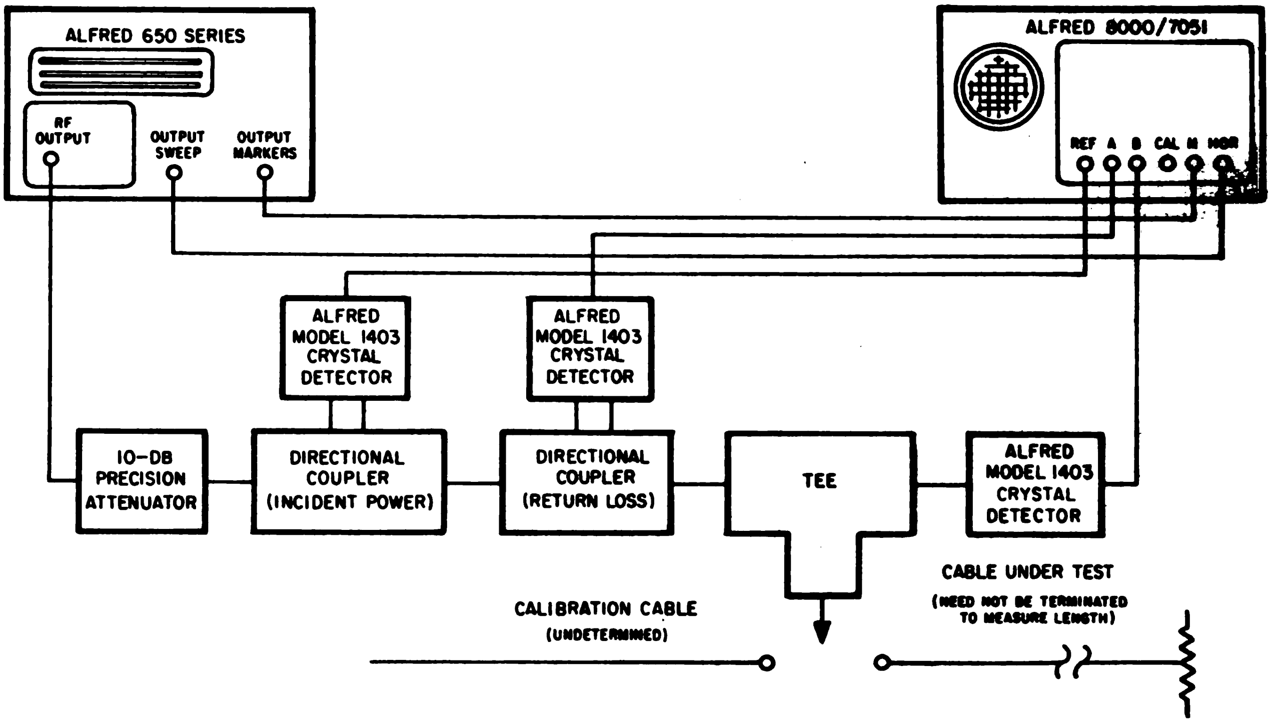
AT.421

Figure 5-46.—Return-loss display.

"needs repair" indications in figures 5-45 and 5-46. Multiplying the 5 2/3 ripples which appear on the oscilloscope by the display calibration factor of 2 feet per ripple will quickly identify the location of the fault (11 1/3 feet from the cable-end connector). Figure 5-49 illustrates a dual-channel display after faults (figs. 5-45 and 5-46) have been corrected. The insertion loss is less than 10 db and the return loss greater than 11 db, indicating that performance is now satisfactory.

Detailed FDR Analysis

With the sweep oscillator output, the transmission system under test, and the crystal detector all connected to the same tee junction, discontinuities and/or termination mismatch in the system reflect some of the incident power. The reflected power combines with the incident signal at the crystal detector, resulting in a changing phase relationship that depends upon both distance to the discontinuity and signal frequency. As the frequency is swept, it changes the number of wavelengths which occupy the


ALFRED 650 SERIES
RF OUTPUT
OUTPUT SWEEP
OUTPUT MARKERS
ALFRED 8000/7051
REF
A
B
CAL
M
HOR
ALFRED MODEL 1403 CRYSTAL DETECTOR
ALFRED MODEL 1403 CRYSTAL DETECTOR
10-DB PRECISION ATTENUATOR
DIRECTIONAL COUPLER (INCIDENT POWER)
DIRECTIONAL COUPLER (RETURN LOSS)
TEE
ALFRED MODEL 1403 CRYSTAL DETECTOR
CABLE UNDER TEST
(NEED NOT BE TERMINATED TO MEASURE LENGTH)
CALIBRATION CABLE
(UNDETERMINED)

AT.422

Figure 5-47.—Test setup for fault-location measurement.

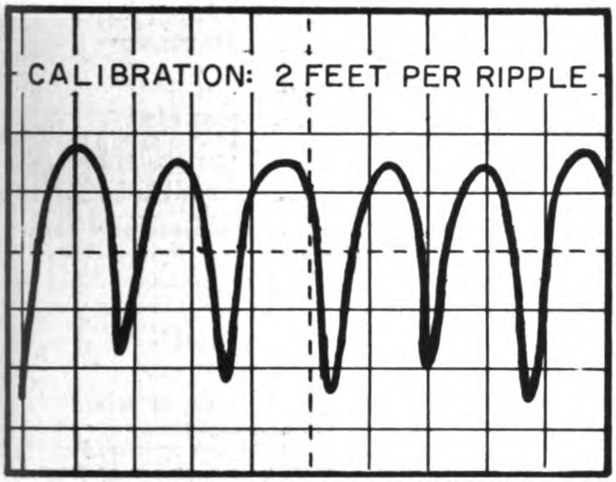
fixed path from the tee to the point of reflection and back. The display thus will show amplitude "ripples" which result from the summing of the incident and reflected signals whose relationship changes with frequency. Figure 5-50 illustrates how the magnitude of the vector sum of these signals, which is the signal level detected for display, varies with frequency.

The resultant display of the varying-magnitude detected signal is actually a logarithmic SWR presentation. The ripple peaks are adjacent VSWR maxima which occur, during the sweep, at each frequency in which the "round-trip" length of the reflected wave path from the source to the defect has changed by one wavelength. The number of ripples appearing across the full width of the display (which is inversely proportional to the frequency separation of adjacent ripples) is a measure of the distance from the discontinuity to the crystal detector. Therefore, direct readout of fault distance is provided when the swept source is operated over a sweep width (ΔF) which is chosen to provide a display calibration (in terms of ripples per foot) compatible with the length of the transmission system under test.

In a coaxial system, it can be shown that the distance to a discontinuity, which may be a fault or the cable end, is represented by the equation

$$D = \frac{492\ K\ N}{\Delta F}$$

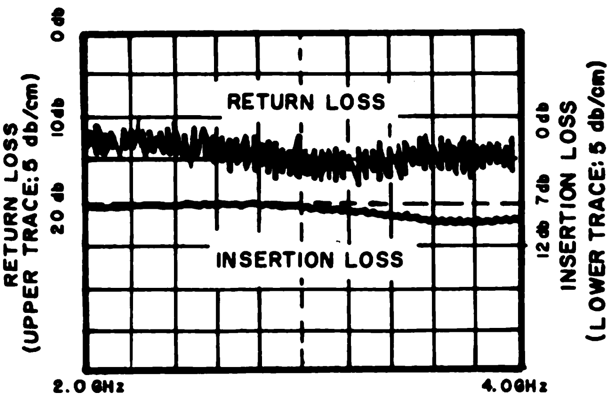
where D is the distance to the fault or cable end in feet; 492 is the half wavelength in feet of a 1-MHz wave in free space transmission; K is the propagation constant which relates the propagation velocity in the coaxial system to the



AT.423

Figure 5-48.—Measuring a cable fault.

velocity in free space; N is the number of ripples observed in the display; and ΔF is the swept-frequency excursion (sweep width) of the signal source in MHz. Note that for any type of cable, F can be selected to equal 492 K, so that the distance in feet is equal to the number of ripples (including the fractional ripples) shown in the display. In waveguide systems, the distance down the waveguide to the fault is represented by the same equation, with K denoting the relation $\lambda/\lambda g$ (λ is the wavelength in free space and λg is the wavelength in the waveguide) at the frequency of measurement.



AT.424

Figure 5-49.—Dual-channel display of a repaired cable.

Cable Measurements

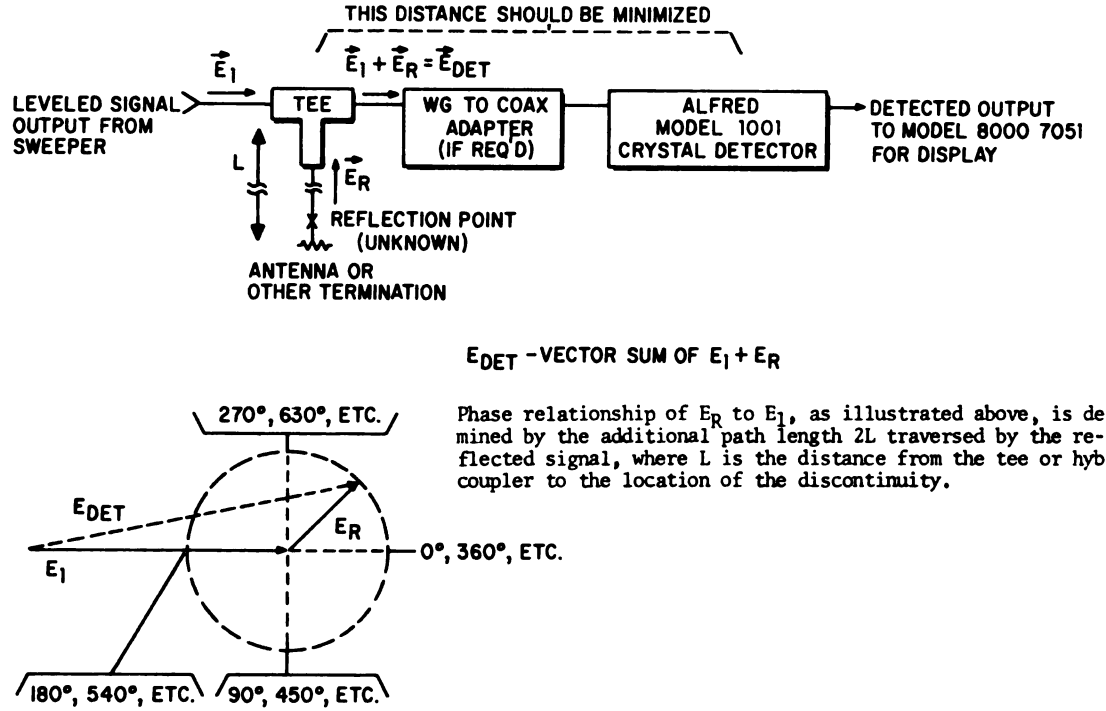
The test setup in figure 5-47 shows that the only variable requiring adjustment is the sweep width ΔF. To calibrate the display in terms of feet per ripple, it is most convenient to select a ratio of 1:1 or an integer factor to give a reasonable pattern for the length of system being measured, such as 1 foot per ripple for a 20-foot cable and 5 feet per ripple for a 100-foot cable. The simplest way to adjust ΔF is to use a known-length "calibration cable" having the same propagation constant as the cable to be tested. For example, if a 10-foot length of cable is used as a calibration cable, a sweep-width adjustment which gives a 10-ripple display calibrates the CRT readout to 1 foot per ripple.

A ΔF setting producing five ripples places calibration at 2 feet per ripple and a ΔF setting producing two ripples result in a calibration of 5 feet per ripple (fig. 5-51).

The calibration cable is a simple device for checking the setting of ΔF. In figure 5-51, the 1-foot-per-ripple, 2-foot-per-ripple, and 5-foot-per-ripple calibrations require ΔF settings of 324 MHz, 162 MHz, and 64.8 MHz, respectively, for a cable with a propagation constant of 0.659. The ΔF sweep width could also be set with a cavity wavemeter.

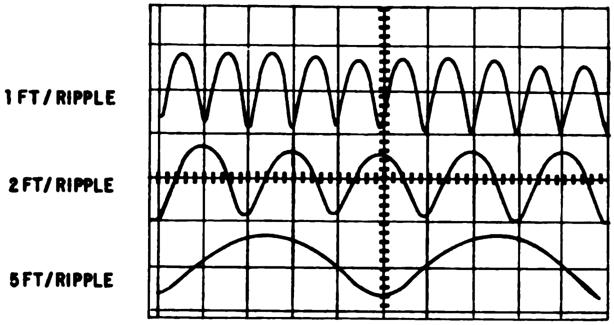
Once ΔF is set, the instruments can make an unlimited number of measurements without readjustment. In testing a variety of cables having different propagation constants, it is unnecessary to readjust ΔF.

Instead, the observed quantity of ripples can be multiplied by the quotient derived from dividing the propagation constants (the new propagation constant divided by a calibration propagation constant). The FDR display shown in figure 5-52, obtained from a 4-foot, 4-inch cable that has a propagation constant of 0.659 is connected to a 96-foot air dielectric cable (unterminated) having a different characteristic


THIS DISTANCE SHOULD BE MINIMIZED
$\vec{E}_I$
$\vec{E}_I + \vec{E}_R = \vec{E}_{DET}$
LEVELED SIGNAL OUTPUT FROM SWEEPER
TEE
WG TO COAX ADAPTER (IF REQ'D)
ALFRED MODEL 1001 CRYSTAL DETECTOR
DETECTED OUTPUT TO MODEL 8000 7051 FOR DISPLAY
L
$\vec{E}_R$
REFLECTION POINT (UNKNOWN)
ANTENNA OR OTHER TERMINATION
E_{DET} -VECTOR SUM OF $E_I + E_R$
270°, 630°, ETC.
E_{DET}
E_R
E_I
0°, 360°, ETC.
180°, 540°, ETC.
90°, 450°, ETC.

Phase relationship of E_R to E_I, as illustrated above, is determined by the additional path length 2L traversed by the reflected signal, where L is the distance from the tee or hybrid coupler to the location of the discontinuity.

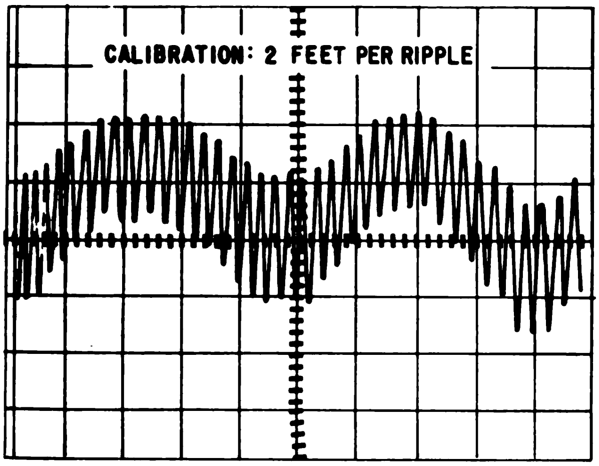
AT.425
Figure 5-50.—Magnitude of the vector sum.



AT.426
Figure 5-51.—Triple calibration displays.

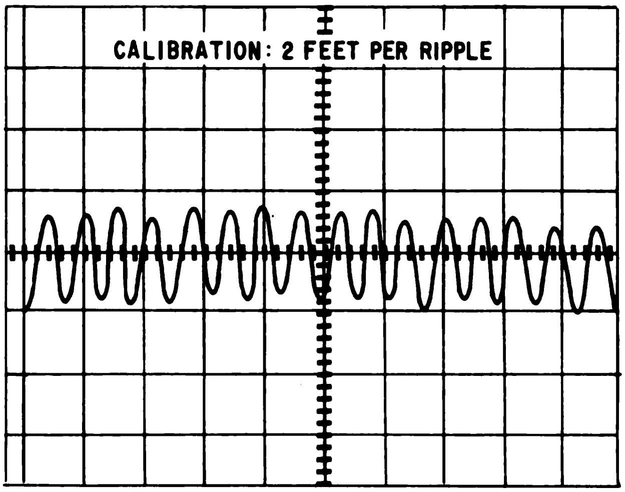
impedance and a propagation constant of 0.84. With a calibration cable having a propagation constant of 0.659, the display is calibrated to provide a readout of 2 feet per ripple. The display shows a 39-ripple pattern resulting from the discontinuity at the distant open end superimposed on a two-ripple pattern and the 2-foot-per-ripple calibration factor is the distance to the mismatched connection. The 39-ripple pattern multiplied by $\frac{0.84}{0.659}$ converts the readout to 50 ripples, which, when multiplied by the 2-foot-per-ripple calibration factor, gives the total which equals the 100-foot distance to the end of the cable run.

After the FDR setup is calibrated, the unknown cable is connected to the measurement tee. A count of the number of ripple cycles in the display is an accurate measure to the cable end or any fault in terms of the foot-per-ripple



AT.427

Figure 5-52.–A 4-foot, 4-inch cable connected to a 96-foot air dielectric cable.



AT.428

Figure 5-53.–Length of good RG-58/U coaxial cable.

calibration. A partial ripple cycle indicates a corresponding fraction of that calibration.

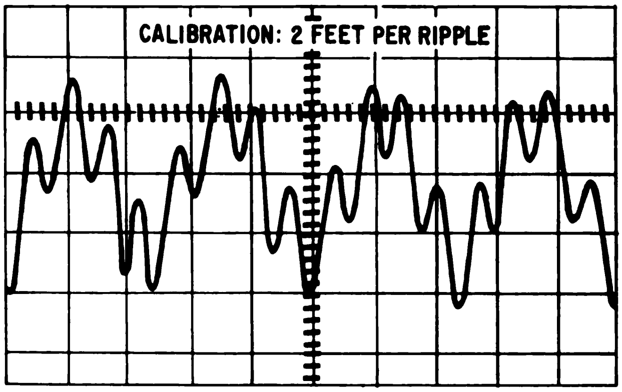
Applications

The speed and simplicity of the FDR measurement can be illustrated with a few examples. Figure 5-53 is an FDR display of a 32-foot, 4-inch length of good RG-58/U unterminated coaxial cable. There are 16 1/4 observed ripples multiplied by the 2-foot-per-ripple calibration, resulting in a readout of 32 feet, 6 inches as the distance to the mismated cable end. (Accuracy is usually better than 5 percent.)

Figure 5-54 shows how the pattern changes when the same cable has one or more discontinuities. In the figure a fault-producing crimp is located 8 feet from the measurement end. A pattern consisting of 16 (and a fraction) ripples (indicating the discontinuity of the open end) is superimposed on a four-ripple pattern (verifying the fault at the 8-foot point).

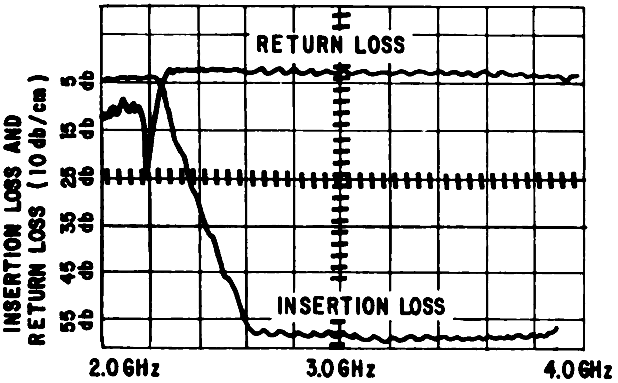
Figure 5-55 illustrates the performance (insertion and return loss) checkout display obtained from an unterminated transmission cable system which has a 2.5-GHz filter between two lengths of cable. This figure also shows the response from a system having a frequency-sensitive discontinuity. The insertion-loss and return-loss displays indicate some discontinuity in the system.

The FDR display (fig. 5-56) locates it precisely. Remember the cable has a 2.15-GHz



AT.429

Figure 5-54.–Length of crimped RG-58/U coaxial cable.



AT.430
Figure 5-55.—Cable containing a 2.15-GHz filter.

low-pass filter in its run. TDR normally would indicate the filter as a fault; with FDR, however, the cable out to the filter can be checked with frequencies above 2.15-GHz. A frequency of 2.6 GHz, well above filter cutoff, was used for the FDR display shown in figure 5-56. If a calibration factor of 2 feet per ripple is used, the displayed 2 1/3 ripples indicate the filter is at a point 4 2/3 feet along the cable. The far end of the cable from the filter to the antenna can be checked with frequencies below 2.15 GHz, as shown in figure 5-57.

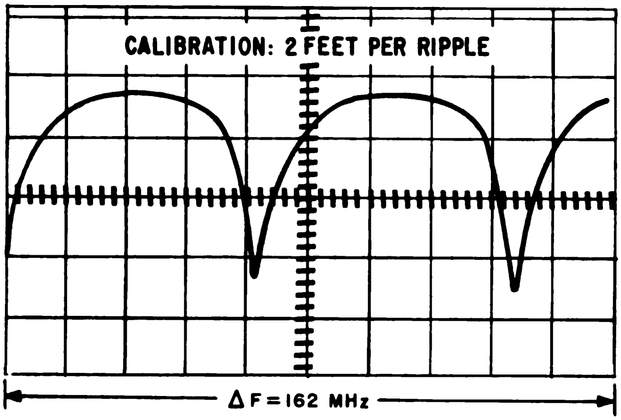
Figure 5-57 is an FDR display of the same cable system used for the displays shown in figure 5-55 and 5-56. With an insertion frequency of 2.1 GHz, which is below the low-pass filter cutoff, the display of 8 2/3 ripples shows that the open-end discontinuity is 17 1/3 feet away. This indicates a slight mismatch at the filter interface below cutoff, characterized by the return-loss trace at the left-hand edge of figure 5-55.

Conclusion

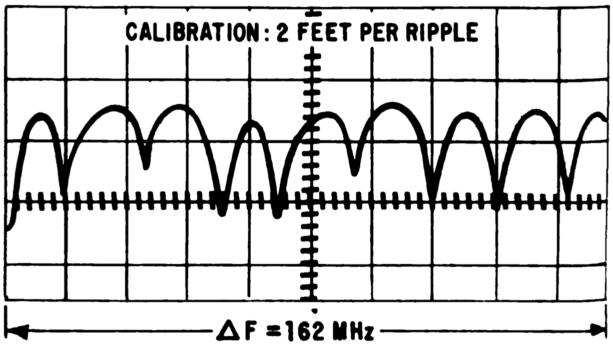
To locate faults and to indicate their seriousness, FDR uses the comprehensive frequency-sensitive information contained in the SWR display, thus making a difficult measurement simple. In addition to providing positive identification of all faults at the frequency of operation, the new system makes possible efficient semiautomatic routine testing of all cables in a complex aircraft.

FDR, because of its technical advantage, adds to the Navy's maintenance techniques and results in additional savings in manpower and materials.

FDR is not only used in aircraft but can also be applied to naval surface ships, submarines, and certain shore installations.



AT.431
Figure 5-56.—Insertion above filter frequency, 2.6 GHz.



AT.432
Figure 5-57.—Insertion below filter frequency, 2.1 GHz.

SPECIAL AVIONICS SUPPORT EQUIPMENT

The numerous and complex operations required for servicing and maintaining radar equipment requires in some instances, numerous classes of support equipment. Therefore, a test set or system that combines the function of several test sets is very practical and desirable. Support equipment has been developed that can be used to maintain or test complete systems in various types of aircraft. Three of these systems are known as Semiautomatic Checkout Equipment (SACE), Versatile Avionics Shop Test (VAST), and Built-In Test (BIT).

SACE

The main purpose of SACE is to check the performance of individual electronic boxes of various electronic systems located in the A-6 and RA-5C aircraft and to isolate malfunctions to a replaceable module or circuit. Each electronic box can be tested without requiring its operation with any of the other boxes of the system. SACE will simulate all the input signals for any box.

SACE consists of six bench installations—the programming test bench, system analyzer test bench, bomb directing test bench, radio set test bench, countermeasures equipment test bench, and flight control set test bench.

The programing test bench (fig. 5-58) serves as the center of SACE to perform the programing of tests and the basic measurements. The system analyzer test bench (fig. 5-59) is used to test major components of the SACE equipment. The other test benches contain the special equipment required for testing and identifying the malfunction to the module or circuit level of the electronic box.

The programing test bench (fig. 5-58) is known as the C93B and has been used for many years. However, a new program comparator has been developed and is in use with the A-6 aircraft. This program comparator is known as the C93M. By the use of advanced microminiaturization techniques the C93M has achieved a 95 percent reduction in both size and weight from the C93B. Refer to figure 5-60 for a comparison of the C93B and C93M program comparators.

Operation of SACE

The semiautomatic operation of the programing test bench is controlled by the operator and a punched tape. During testing, the tape programer automatically controls the signal selection, measurement, counting, and comparison functions for the test. Programed information and control signals are fed to the associated test benches from the programer.

The operator is furnished a book containing brief instructions for routine test procedures and an appendix giving detailed information on each test so that he can interpret a failure of any particular test. The operation is semiautomatic. The operator is required to set switches and read instruments at certain points during the procedure. Having set the switches as instructed for the first test, the operator presses the START switch on the control panel and the programing test bench goes through the first set of tests. When another switch setting is required or an instrument is to be read, the programing test bench stops and the operator reads his operating instructions. When the test results have been resolved to a digital form, they are sent to the comparator (fig. 5-58) which has been previously programed with two sets of limits. These limits are stored in upper and lower limit registers. If the test results pass through the comparator within limits and if in normal mode of operation, the tape programer receives a signal to go ahead to the next test; if the results do not pass, the tape programer will stop, if so programed. The comparator will also produce information to illuminate the HI (high), LO (low), or GO (go) lamps on the control panel where readout can be accomplished by visual means. There are two rows of Nixie lamps that give the test number, polarity, and actual value. Normally they will be operating so fast that the last number may be a blur, but the higher valued lamps may be distinguishable. The manual controls for the programing test bench operation are also located on the control panel.

VAST

The VAST system, the AN/USM-247, curbeing installed aboard naval aircraft carriers is meant to cope with the continually changing character of avionic testing. The Navy estimates

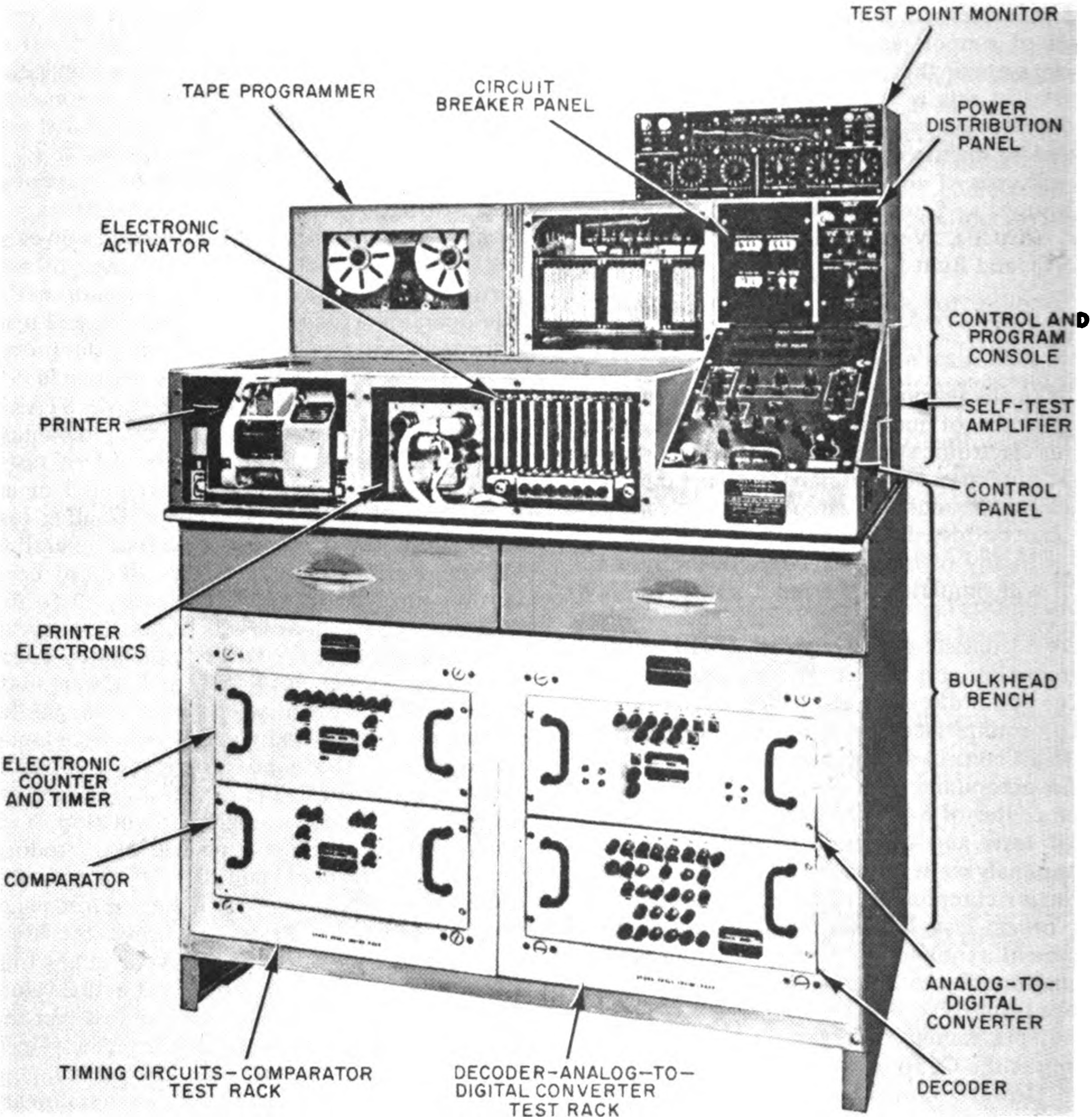


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Figure 5-58.—SACE programing test bench.

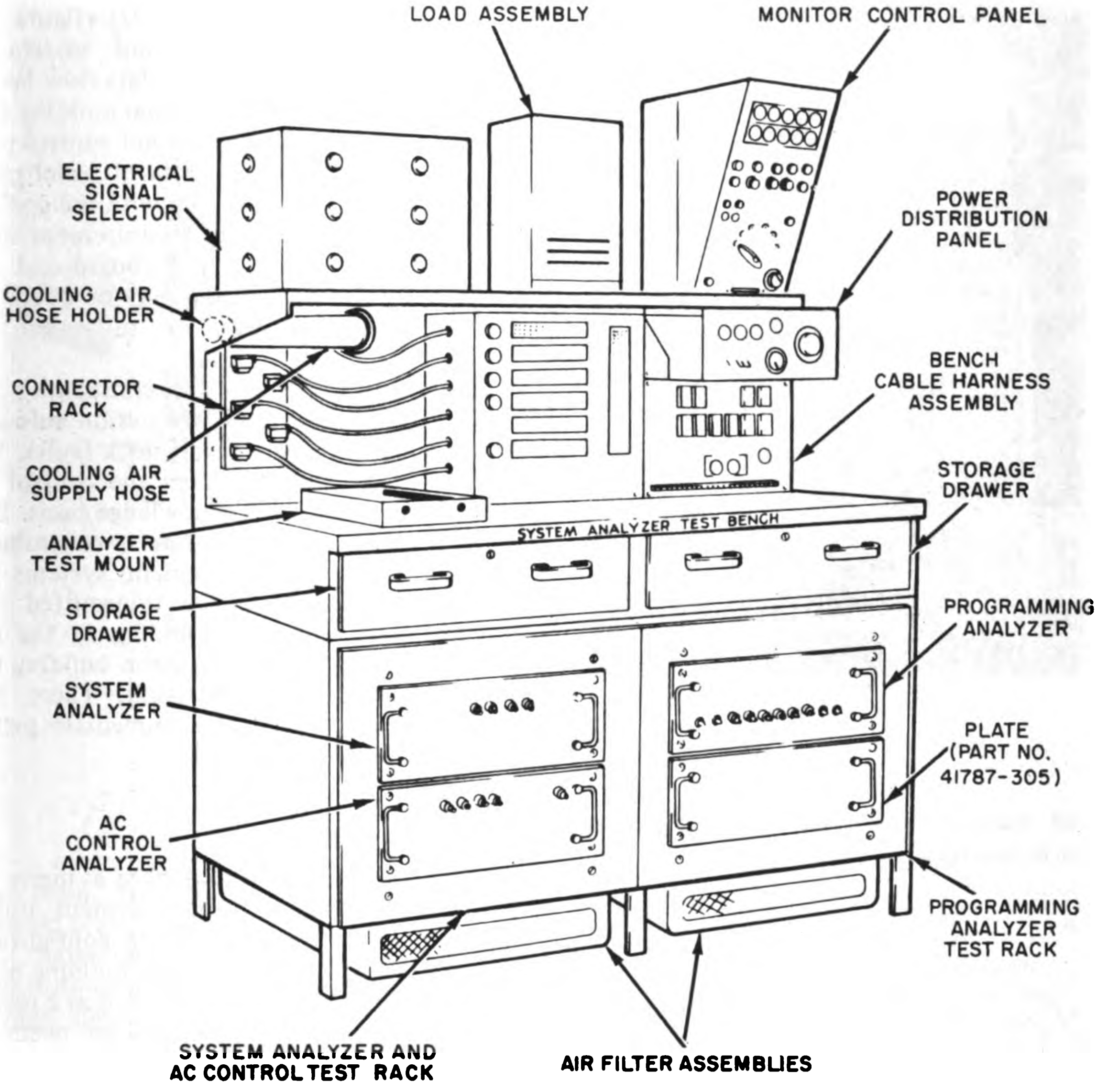

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Figure 5-59.—SACE system analyzer test bench.

that VAST will significantly reduce the space required by equivalent special and manual support equipment.

To better understand how this is possible, take a look at a typical VAST station. In its basic form, a VAST test station is assembled from an inventory of functional building blocks which furnish all the necessary stimuli and measurement capability to check current naval avionics equipment. As new avionics are developed and introduced, the test station configuration may be modified and, as it becomes

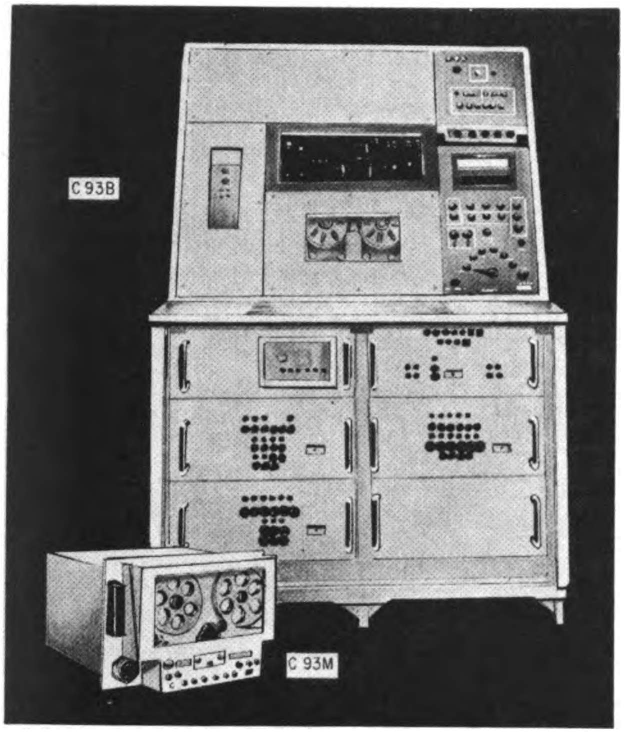

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Figure 5-60.—Comparison between the C93B and C93M program comparators.

necessary, new building blocks are added to furnish new parameters or greater precision to existing capabilities.

A typical VAST test station consists of a computer subsystem, a data transfer unit, and a stimulus and measurement section containing functional building blocks configured to meet the intended test application. Figure 5-61 shows a typical carrier-based VAST test station.

The carrier-based test station is controlled by a computer sybsystem which executes test programs to assure accurate and satisfactory testing. The computer sybsystem includes a general purpose digital computer which not only executes test routines but also provides a diagnostic and computational capabilities as well. It also processes data and furnishes a permanent record of test results. Two magnetic tape transports provide rapid access to avionic test programs and immediate availability of VAST self-check programs.

The data transfer unit (DTU) (figure 5-62) serves as the operator-machine interface. It synchronizes instructions and data flow between the computer and the functional building blocks and also contains the display and control panels.

The data transfer unit control panel permits the operator to communicate with the computer and with the stimulus and measurement section of VAST by means of a keyboard and mode select key. The test station may be operated in manual, semiautomatic, or fully automatic modes.

The data transfer unit also contains a maintenance panel which monitors station auto-check results and indicates building block faults. Transmission of instructions from the control computer is on a request/acknowledge basis. Essentially, then, the response rate is controlled by the stimulus and measurement systems. This permits instructions to be transmitted at an asynchronous rate corresponding to the maximum frequency at which a given building block or avionics unit can respond. There is no requirement, therefore, for immediate program storage in the DTU.

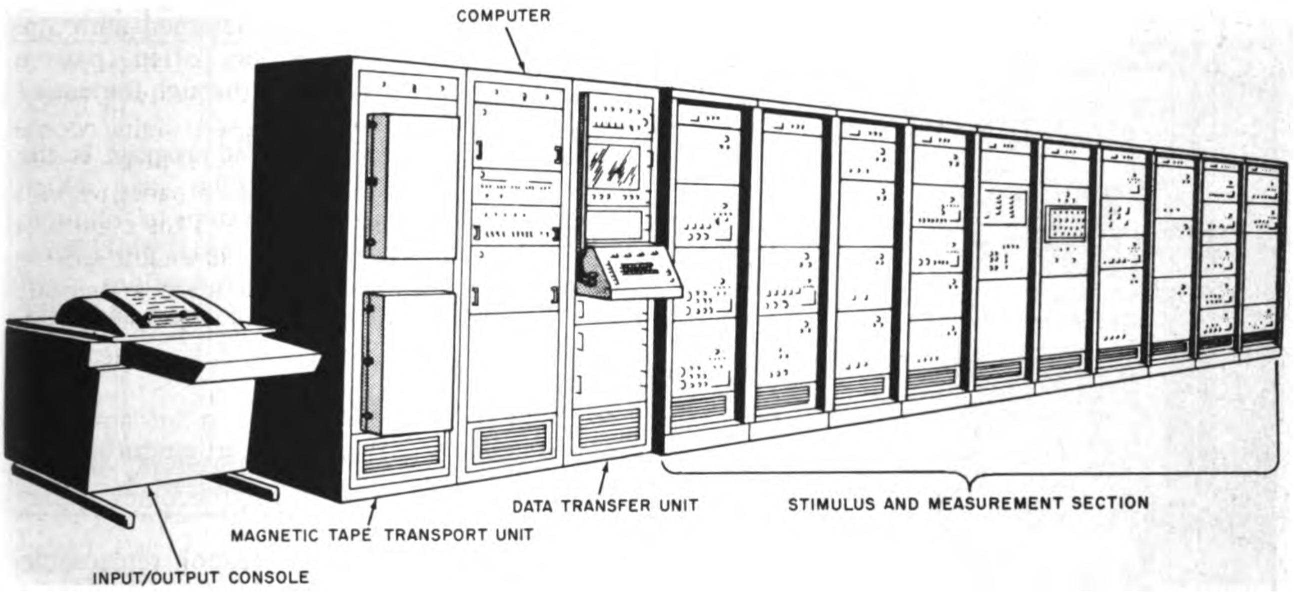
Typical Station

A VAST test station may have as many as 14 racks of stimulus and measurement building blocks (fig. 5-63). Large station configurations may contain as many as 17 core building blocks. Core building blocks are designated as a result of high-use factors or because they are needed for self-test requirements.

Building blocks not in the core category are usually selected in accordance with specific test requirements relevant to the shop operations or avionic equipment on board ship.

In general, the location of such peripheral building blocks is flexible and in order to maintain standardization between VAST stations, the effects of building block interconnection cable losses and switches have to remain within predictable limits. It is the purpose of the core concept to assure this.

VAST was designed with ease of maintenance a primary objective. In addition to the modularized design of VAST building blocks, there are three levels of fault detection which are in-


COMPUTER
DATA TRANSFER UNIT
STIMULUS AND MEASUREMENT SECTION
MAGNETIC TAPE TRANSPORT UNIT
INPUT/OUTPUT CONSOLE

AQ.13

Figure 5-61.–A typical carrier based VAST test station.

tended to insure rapid confidence tests and easy fault location. The three levels of detection are auto-check, self-check, and self-test.

Fault detection may be initially uncovered through auto-check. The auto-check is inherent in the logic and control design of the test station and includes verification of instructions and fault monitoring. Auto-check is carried out on a continuous basis during station operation and, when a fault occurs, testing is interrupted.

The second level of VAST fault detection is self-check. A programed sequence which is initiated by the VAST operator through the DTU keyboard, self-check may be either internal or system level. Internal self-check measures the ability of a building block to perform against its own internal standards. System self-check requires the use of two or more building blocks in a test configuration selected to isolate faults within the test set up.

The self-check philosophy utilized to verify the operation of VAST is based upon confirmation of key system elements first, then employing these elements to check the remaining building blocks. Fundamental core building blocks are checked by means of internal standards. Once satisfactory performance has been assured, their capabilities are used to check the remaining building blocks. The check-out of non-core building blocks is then accomplished by using any combination of core measurement or stimulus building blocks.

The final level of VAST fault detection is self-test. This is a series of test programs used to locate faults within a building block. If a building block has been found to contain a malfunction as a result of the self-check routine, then self-test programs are conducted by removing the faulty building block from the VAST rack and connecting it to the test station in the same manner as if it were a unit under test.

To assure optimum support by VAST, it is essential that avionic equipment be designed to

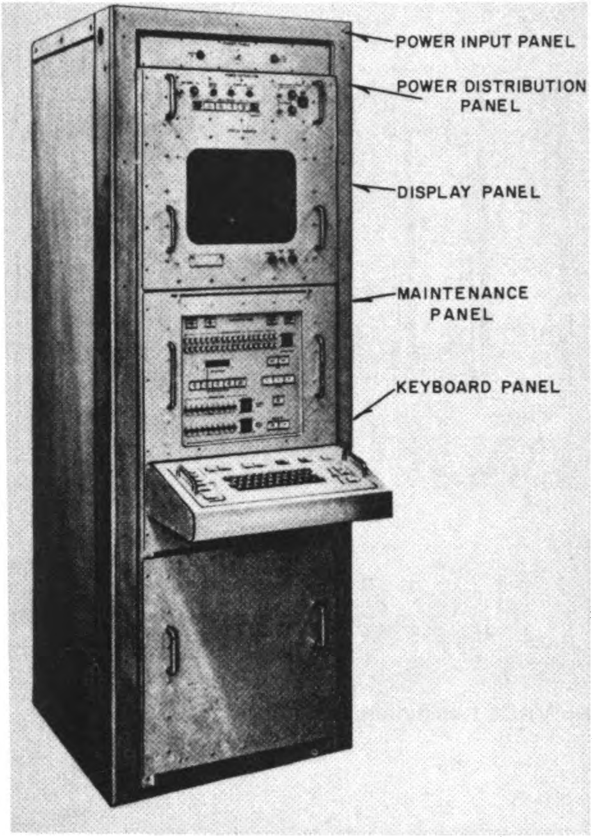


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Figure 5-62.—Typical data transfer unit.

be adaptable to automatic testing. Moreover, test programs must be prepared which are compatible with VAST performance characteristics.

Interconnecting Device

Included in the program design is the all-important interconnecting device design. In its simplest form, the interconnecting device consists of an adapter cable, which connects the unit under test (UUT) to the VAST interface. In some cases, however, it is necessary to introduce—as part of the electrical interface in the interconnecting device—passive and active circuits to change impedance levels or to amplify low signals. Ordinarily this is not required if the avionic equipment has been designed with the requirements for VAST. Very often, passive circuit functions are obtained through the use of standard plug-in modules.

The last element of the test program is the instruction booklet or microfilm strip which details for the operator all the steps to follow in testing any given unit—from initial procedures such as hook up and clearing operations, right down to the final stages of disconnect and UUT closeout.

Operation of a VAST Station

In a typical VAST test procedure, ease in operation of the actual testing becomes apparent.

The initial set-up of the weapon replaceable assembly, including removal of dust covers, cooling provisions, and detail connections to the interface device, may be made off-station in order to minimize disruptions of station operators. Final connections between the VAST stations interface panel and the UUT are made in a few moments directly at the station.

The operator begins testing by selecting the code which initiates the test program. Prior to applying power or stimulus to the UUT, continuity tests are quickly run to insure that the proper test program has been selected and that no conditions exist which will damage the VAST station or the unit under test once active tests are started. If everything checks out o.k. then the testing proceeds automatically. The operator only has to respond to instructions that appear on the CRT display. The program will not stop until a fault is encountered or at a program halt.

The purpose of programed halts is to allow manual intervention during the course of testing to make adjustments and observations. When the identification of faults and the operator's instructions are required—such as interpreting a complex waveform—the operator may be referred to the test program instructions. Upon completion of the test program, the CRT display indicates any closeout procedures.

The VAST test station is completely autonomous and normally is operated under computer control in a fully automatic mode, stopping only as previously mentioned. Of course,

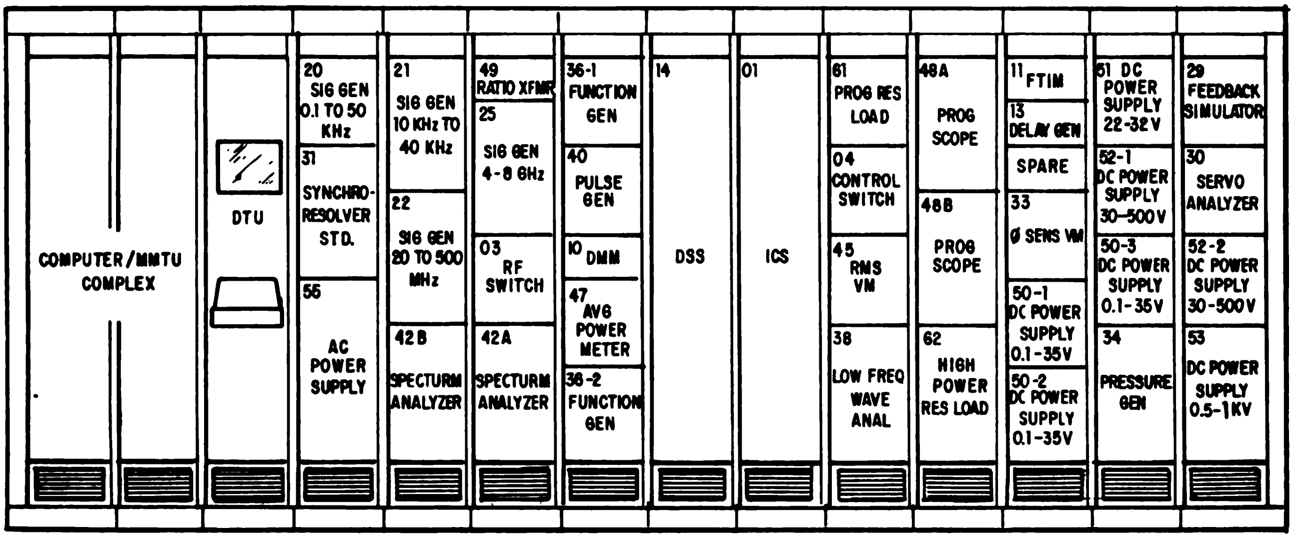

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Figure 5-63.–VAST test station with building blocks.

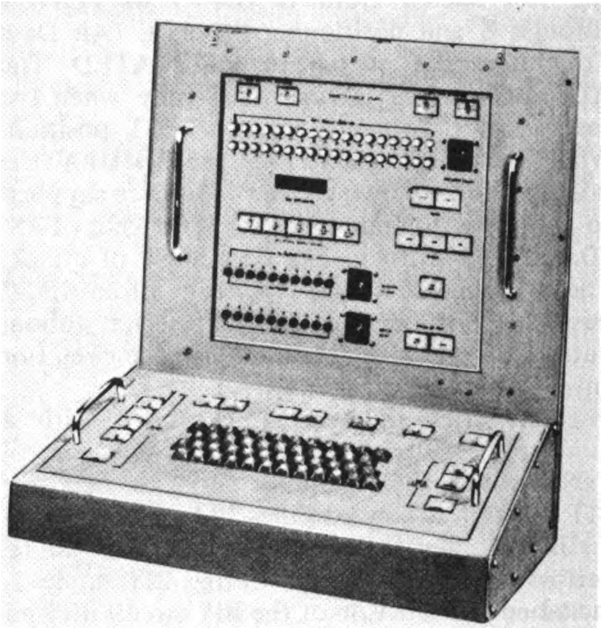
the operator can select any one of the three semiautomatic modes or, if he so chooses, a manual mode.

The semiautomatic modes include a one-group, one-test and one-step mode. These auxiliary modes permit detailed observation of various test sequences and are useful in performing work-around procedures, reconciling differences in equipment and program mode status and the verification of repairs.

In the manual mode, the test station is completely off-line with respect to the computer. Instructions are introduced by the operator through the keyboard on a one-word-at-a-time basis (figure 5-64). Although the manual mode is never used for avionic testing, it is useful for debugging new programs, integrating new building blocks into the station, and for performing self-check operations on some of the building blocks.

BIT

In aviation weapons systems of today, special built-in test (BIT) circuits are installed to provide the technician and operator with an evaluation of the overall system performance. When



AQ.16
Figure 5-64.–Typical VAST control panel.

BIT is used in performance testing, the operator or technician can determine if the system is operating properly with the aid of an overlay pattern on etched markings on the indicator face and other meter indications. The test requires no other test equipment. This type testing requires that maintenance personnel have a thorough knowledge of the entire system operation and be able to evaluate the test indications as presented on the radar scope and other indicators.

An advantage of BIT is that the operator may test the system in flight and provide information during the debrief concerning special symptoms of troubles that may occur only when airborne.

BIT will provide an evaluation of the overall system performance; however, this cannot be used to replace the minimum performance checks found in the Maintenance Instructions Manuals.

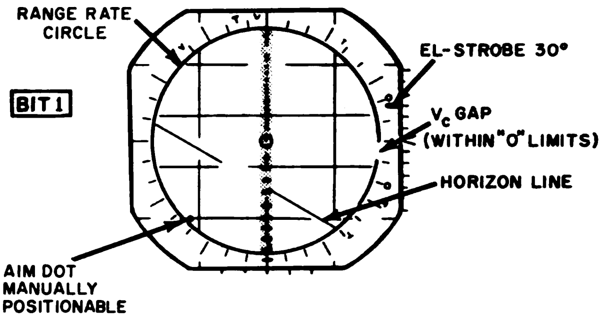


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Figure 5-65.—Indicator display of BIT position 1.

Operation of a Typical BIT System

To demonstrate the purpose and application of the BIT system, the system found in the F-4 aircraft is explained in a brief summary.

BIT checks consist of manually moving the radar power switch to TEST, and then moving the test switch from O (OFF) to TEST 1 through 8 and positioning the ADC (Air Data Computer) BIT switch to SIMULATED. The ADC BIT switch is functional only when the radar power switch is in the TEST position. When the ADC switch is in the SIMULATED position, the following fixed inputs are supplied to the radar for test purposes: 800 knots TAS, 40,000 feet altitude, and zero angle of attack. The BIT checks simulate the firing of an AIM-7 missile loaded on the right aft fuselage station, but do not check the continuity of the circuit or any other missile station.

Each series of test is associated with a numbered position of the radar set control TEST switch. For simplicity purposes, only one BIT position will be covered—BIT 1. The following is a summary of the built-in test that can be performed on the system during BIT mode 1, including the function of the BIT circuit utilized during the test and the meaning of the readout.

Figure 5-65 displays the pattern found on the radar indicator during BIT position 1.

The radar set simulated target circuits generate a series of calibrated radar targets 1 mile apart and present them on the indicators. Each target is 1 db less in power than the previous one. By counting the number of targets visible, a measure of receiver sensitivity is obtained. Since the targets are sampled by a calibrated waveguide and crystal delay line system at the pulse magnetron output, the sum of the power output, receiver minimum discernible signal, and indicator sensitivity are measured to an absolute reference. By changing the position of the CLUTTER switch and observing the number of visible targets, receiver sensitivity is checked during receiver clutter elimination conditions.

With the antenna searching, a 30°-roll and a 30°-climb command is applied to the servo plate. The operation of the horizon line and search stabilization system is checked through observation of the search presentation. The position of the horizon line is compared to the diagonal limits etched on the face of the indicator.

When the action switch is depressed, a BIT circuit introduces a decreasing range voltage that causes the range strobe on the indicator to sweep inward at a fixed rate. By positioning the range strobe beyond the weakest detectable target before lockon is attempted, a measure of lockon sensitivity is obtained when the range strobe sweeps in and the system locks on a target. Since the range tracking gate is positioned along with the range strobe, the ability of the radar to acquire a moving target is also checked. Since no simulated antenna modulation is present on the delay line signal in this test, the antenna is prevented from obtaining angle lockon and instead, is placed under manual control while range lock is maintained. By positioning the CLUTTER switch, acquisition in normal or heavy clutter is checked. By locking on a strong target, the AGC action in reducing background noise is checked.

With the radar locked on a target, the radar set group readout is displayed on the indicators. At this time, a d-c voltage proportional to the amplitude of the coding and ranging signal is sent to the computer, then to the VC (velocity closing) gap deflection circuits. The output is interlocked in such a manner that the CW transmitter must be operating and the ASE (Allowable steering error) interlock closed. If the VC gap is positioned between 2:20 and 3:40 o'clock on the range rate circle, the CW transmitter coding and ranging and ASE interlock are working properly.

When the radar is in BOMB position, the STC (sensitive time control) varies receiver gain as a function of range so that signals from equal size targets at different ranges will appear with equal intensity on the display. If rotating RDR RCVR GAIN from fully ccw to fully cw causes the targets to appear toward the bottom of the indicator as gain is increased, the STC is working properly.

PROCEDURES FOR OBTAINING REPAIR AND CALIBRATION OF SUPPORT EQUIPMENT

The Secretary of the Navy requires that adequate calibration equipment and facilities be provided to maintain support equipment at optimum performance levels and prescribes coordinated technical requirements for the Navy-wide calibration program which promotes maximum economy by utilizing existing facilities whenever feasible.

The Naval Air Systems Command has set a policy that all test and measuring equipment under its cognizance will be calibrated periodically and that participation in the established calibration program is mandatory for all Naval Air Systems Command Headquarters managed activities and Navy inspection activities.

Operating activities and training units to which NavAir support equipment is provided for determination of operability and performance of naval air material have the responsibility of insuring that such support equipment is calibrated within the specified periods or exchanged for calibrated units. Each Naval Air Systems Command Representative provides for the scheduling of weapon system support equipment, including ready-for-issue avionics test sets, into those Navy calibration laboratories under his cognizance. Also they stock and issue labels, tags, and information pertaining to the equipment's use and other technical data on the NavAir calibration program.

Qualification, repair, and calibration of test and measurement equipment should be accomplished at AIMD to the maximum extent possible, depending upon the limitations of personnel skills, and the availability of technical publications, spare parts, and facilities. If repair and/or calibration is determined to be beyond the AIMD's capability, defective equipment should be forwarded to the cognizant Naval Calibration Laboratory for repair and/or calibration.

All activities having support equipment requiring the qualification/calibration services should insure that a current inventory of all assigned test and measurement equipment is maintained within the activity displaying when the unit was calibrated and the next due date.

NavAirSysCom directs that all laboratory standards and test and measurement equipment within the calibration program have servicing labels or tags attached. These labels will indicate when the unit was last serviced, by what activity, when the next servicing is due, and special conditions of use. Figure 5-66 displays the labels and tags used in the Navy Calibration Program.

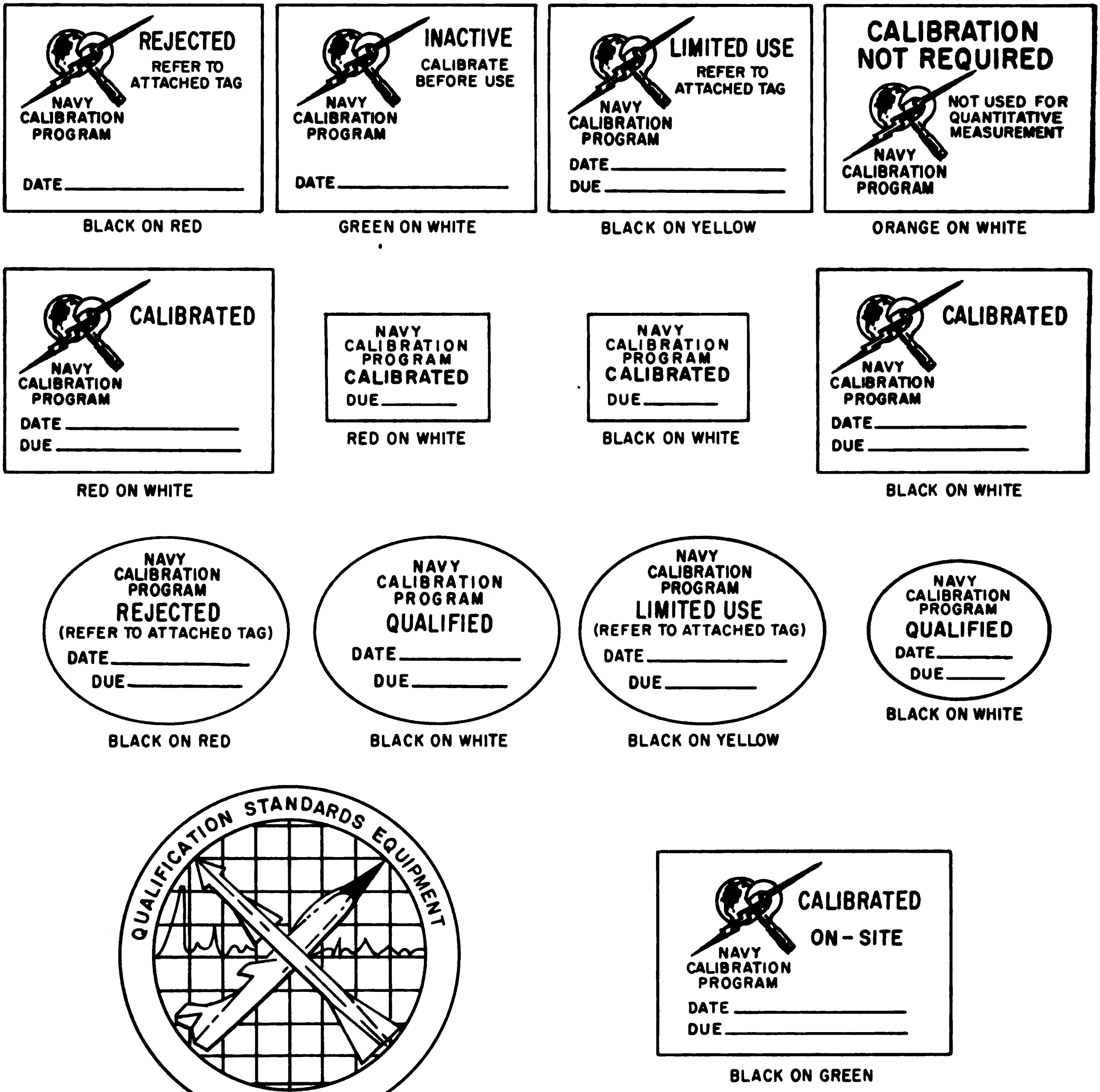

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Figure 5-66.—Labels and tags used in the Navy Calibration Program.

CHAPTER 6

ANTENNAS AND WAVEGUIDE PLUMBING

As an Aviation Fire Control Technician First Class or Chief, you may be required to supervise and instruct others in the maintenance of antennas and waveguide systems. Therefore, it is essential that you have a knowledge of antennas and waveguide principles and their application in aviation fire control equipment.

The fundamental principles of operation of antennas and waveguides are covered in chapter 7 (Waveguides and Cavity Resonators) and chapter 10 (Duplexers and Antennas) of Basic Electronics Vol. 2, NavPers 10087-C, and are not discussed in this chapter. Therefore it is recommended that the material in Basic Electronics be reviewed before continuing in this manual. The material presented in this chapter is relative to antennas and waveguide systems employed in aviation fire control equipment.

ANTENNA CHARACTERISTICS

After an RF signal has been generated in the transmitter, there must be a means of radiating this signal into space, and a means by which it may be intercepted (picked up) for use by the receiver. The device which fulfills both of these requirements is the ANTENNA. The major purpose of a transmitting antenna is to convert the transmitter's RF energy into electromagnetic fields suitable for propagation into space as efficiently as possible. The major purpose of the receiving antenna is to intercept the reflected electromagnetic fields from the target(s) and to change these fields into an RF signal which the receiver is capable of accepting and amplifying.

The process by which the RF energy is converted into electromagnetic waves and radiated into space is called PROPAGATION. Certain basic concepts of antenna propagation are included in Basic Electronics, Vol. 1, chapter 29. These basic concepts should be thoroughly understood.

In the study of this chapter, it should be kept in mind that the subject matter field is broad and no attempt at complete coverage is made. Rather, only such background information that will be of help to the AQ is included. In many instances, the AQ will have the assistance of field engineers, or he will at least have specific instructions on how to perform many jobs. Therefore, he will, in practice, need much of the information contained in this chapter only as a necessary background.

DIRECTIONAL PROPERTIES

One of the most important characteristics of a radar antenna is its directivity. An antenna may radiate energy equally well in all directions or it may radiate in one specific direction better than other directions. However, all antennas are directional to a certain extent—some only slightly and others considerably more.

In aviation fire control radar, the directivity of an antenna is an important factor. An antenna that is highly directional will radiate a maximum amount of energy in a specific direction. Thus, maximum illumination of the target is accomplished. Maximum illumination of the target or concentration of the radiated energy will result in greater range capabilities of the radar set, better target definition, and greater accuracy in determing the position of the target. Since an antenna receives from the same direction that it radiates, the position of the antenna at the time of target reception is indicative of the relative target position.

There are several methods of controlling the directivity of an antenna in its design. Most antennas found in aviation fire control radar employ a parabolic dish type device as a reflector for the radiated energy. It serves to reflect the radiated energy in much the same manner that light rays are reflected.

The degree of directivity of an antenna is referred to as its beam width. If an antenna is capable of radiating a cone of energy with a 3° apex, the antenna has a 3° beam width in both the vertical and horizontal planes.

The use of a narrow beam width will result in more accurate target position determination. Most fire control radar antennas radiate energy into space in narrow pencil type beams or lobes, especially those used in the detection of airborne targets. Figure 6-1 is an illustration of such a radar beam.

It may be noted that the larger the reflector, in terms of wavelength, the narrower is the beam width. The actual physical size, however, is limited by the space available in the aircraft. Therefore, the tendency toward higher frequencies enables us to use a smaller "dish," allowing greater flexibility in locating the antenna in the aircraft; or a larger dish (in terms of wavelength) may be used with an improvement in beam width.

In radar bombing equipment, it is desirable to cover a larger surface area ahead of the bombing aircraft. Thus, a beam that is narrow in the horizontal plane and wide in the vertical plane is desirable and results in a narrow blade type beam. Accurate directional characteristics in the azimuth plane will still be maintained with this type beam.

SCAN PATTERNS

Figure 6-2 is an illustration of a typical box type intercept scan pattern. The antenna radiates a conical type beam of approximately 9° which, when added to the 6° vertical "nod," gives the antenna an automatic 15° elevation coverage as it scans back and forth in azimuth. By use of an operator's control, the antenna may be made to scan at any elevation angle within the limits of the equipment.

The degree of azimuth scan may also be selected as desired by the operator in some equipments. As shown in figure 6-2, the operator may select one of the following azimuth scan patterns:

1. Wide—approximately 130°
2. Narrow—approximately 80°
3. Left—approximately 75°
4. Right—approximately 75°

In many aviation fire control radar sets, the conical type radar beam is caused to rotate (or nutate) as it scans a selected area. Figure 6-3 illustrates a nutated radar beam and the resultant coverage. The radar beam is caused to rotate in a circular motion at a specific rate by a spin motor. The spin motor mechanically drives the antenna radiator or antenna feedhorn in a circular motion and thus enlarges the illuminated area. (It should be remembered that the values shown in figure 6-3 are typical and may vary with different equipments.)

Typical scan patterns found in aviation fire control equipment are shown in figure 6-4 (A) and (B). Note that the antenna is also scanned vertically in figure 6-4 (B).

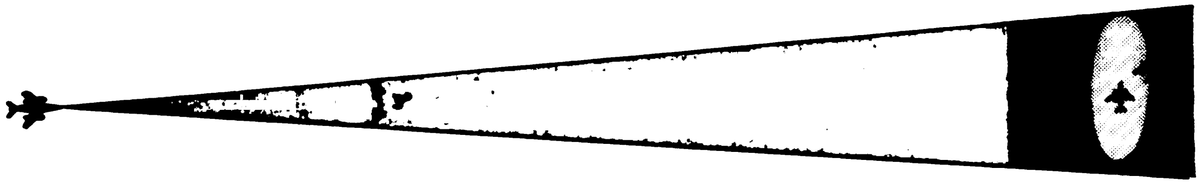

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Figure 6-1.—Pencil type radiation pattern.

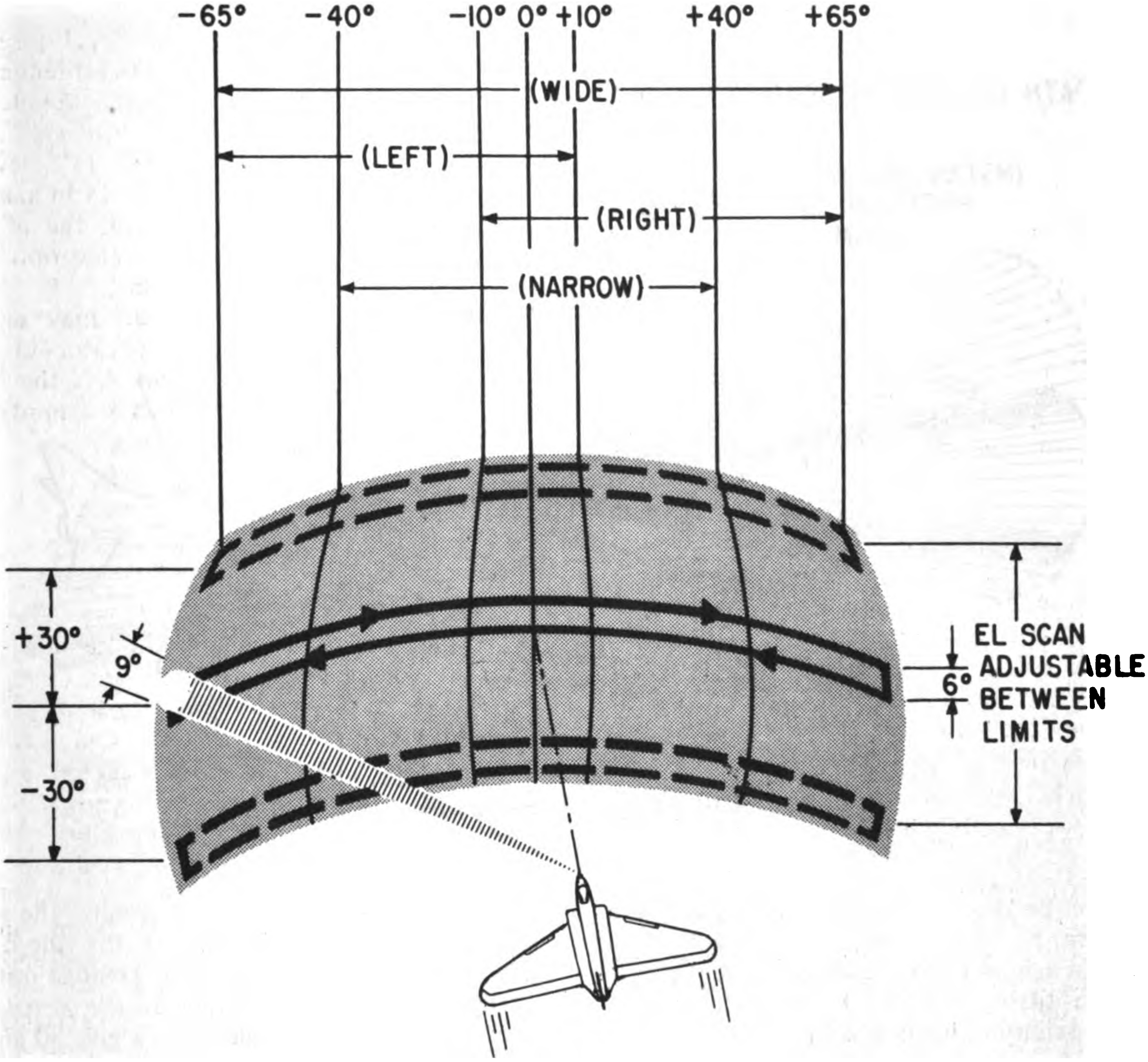

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Figure 6-2.—Conical beam sector scan.

This type scan is almost always controllable to the extent that any sector within limits of the equipment may be scanned as desired. Antenna scan patterns are covered further in chapter 8 of this manual.

ANGULAR DETERMINATION

The measurement of the direction of a target from the radar system is usually given as an angular position. The angle may be measured from true north if the installation is stationary, or with respect to the heading of the aircraft containing the radar set. The angle at which the echo signal returns is measured by utilizing the directional characteristics of the radar antenna system.

The simplest form of antenna for measuring azimuth or bearing is one which produces a single lobe pattern. The system is mounted so

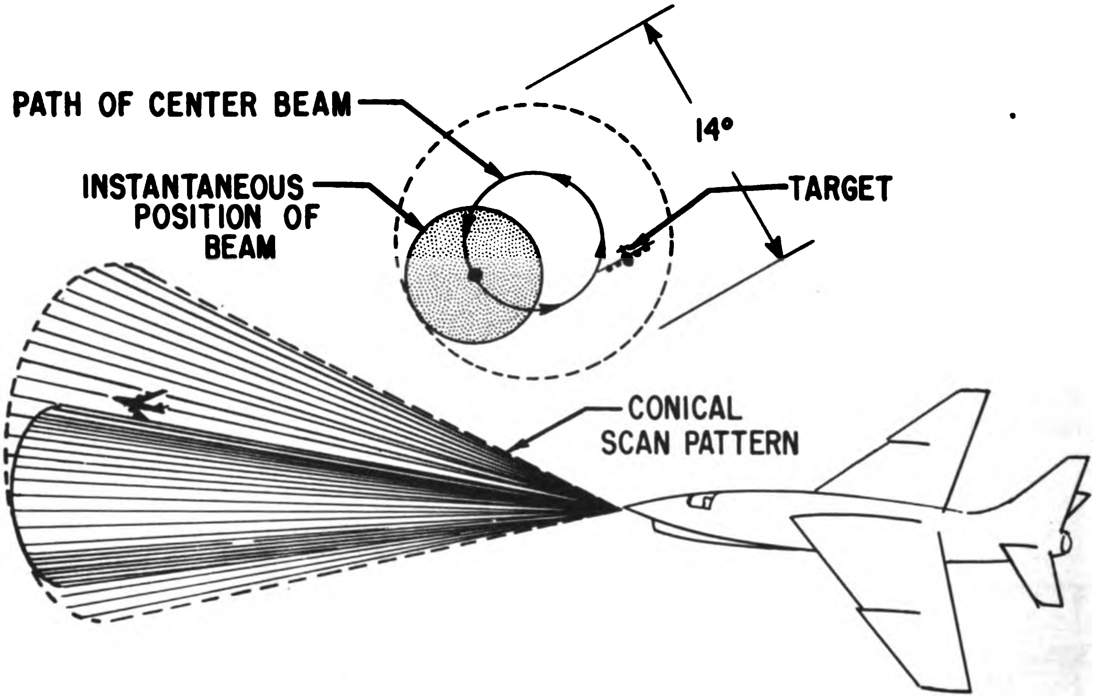

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Figure 6-3.—Rotating beam pattern.

that it can be rotated. Energy is directed across the region to be searched, and the beam is scanned in azimuth until a return signal is picked up. The position of the antenna is then adjusted to give maximum return signal.

Figure 6-5 shows the receiving pattern for a typical radar antenna. Relative signal strength is plotted against angular position of the antenna with respect to the target. Maximum signal is received only when the axis of the lobe passes through the target.

The sensitivity of the single lobe system depends on the angular width of the lobe pattern. The operator adjusts the position of the antenna system for maximum received signal. If the signal strength changes rapidly with angular rotation, the accuracy with which the on-target position can be selected is great. Thus, in figure 6-6 the relative signal strengths A and B have very little difference. If the energy is concentrated into a narrower beam, the difference is greater and the accuracy better.

In the single lobe antenna system, the signal strength varies more rapidly on the side of the lobe than near the axis. The greatest rate of change of signal strength per degree of rotation occurs between the angles which give 50 and 85 percent of maximum. Radar systems designed for gun laying for fire control require the highest possible accuracy in measuring azimuth angles. The multiple lobe system achieves this accuracy by using two or more lobes to form the antenna system pattern.

The principle of the double lobe system is illustrated by using two separate antennas whose lobe axis are displaced by some angular distance (fig. 6-7). The two lobe patterns intersect at one point only, known as the crossover point, at which equal signals are produced by the two antennas for this particular azimuth. At all other positions of the array, unequal signals are produced. When the target is in position A, the echo signals strength received by lobe 1 is proportional to Y, and that received by lobe 2 is

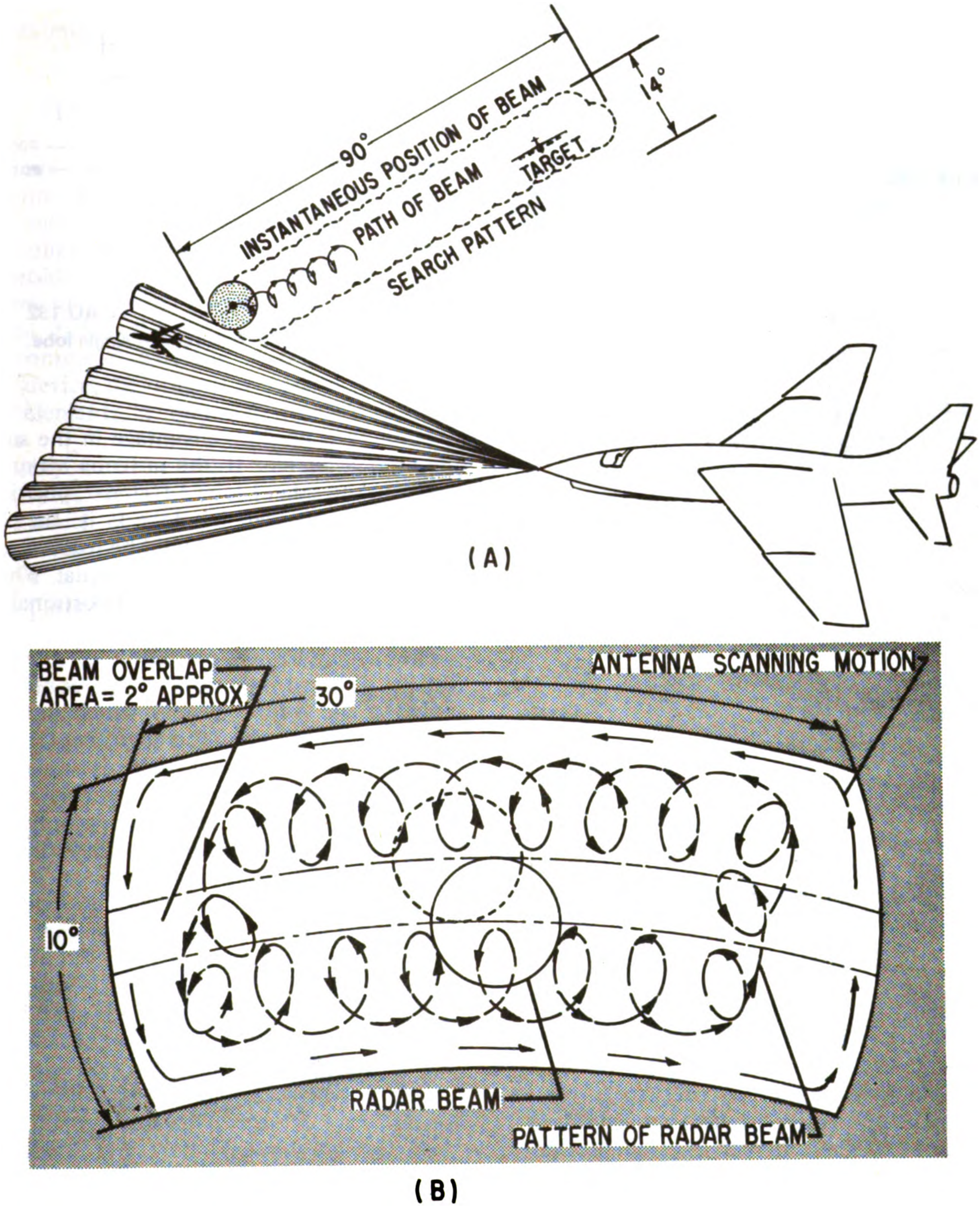

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Figure 6-4.–Antenna coverage patterns.

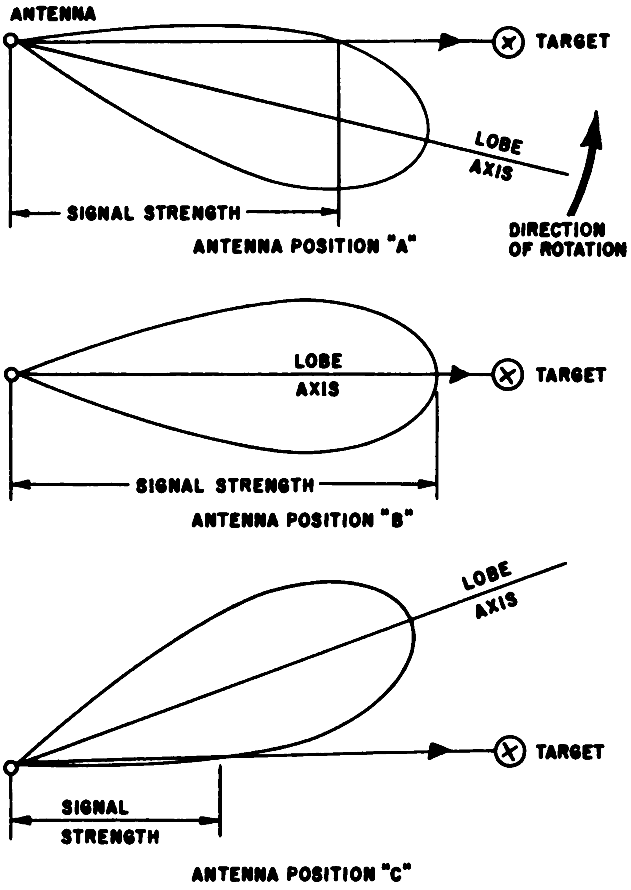

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Figure 6-5.—Relationship between beam axis and target bearing.

proportional to X. If the antenna is rotated so that the target is in position B, the signal from lobe 1 decreases to an amplitude proportional to X, while that from lobe 2 rises to a value proportional to Y. At position C, between these two positions of the antenna, the signals from the two lobes are equal and proportional to Z and the antenna system is on the bearing of the target.

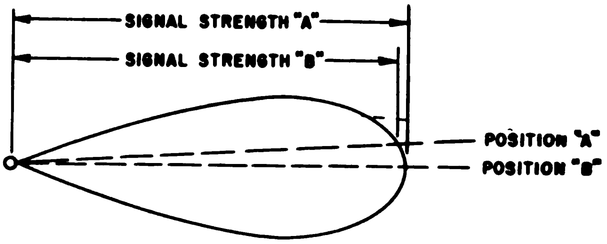

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Figure 6-6.—Accuracy of single lobe.

The use of two lobes instead of a single lobe greatly increases the accuracy of azimuth measurement. The amount of increase depends on the configuration of the antenna array. In addition to the greater accuracy of the double lobe, there is another advantage in the sense of direction available. If the antenna array is off target on the side of lobe 1 (fig. 6-7, position A), the signal received by lobe 1 is the larger. Therefore, the antenna should be rotated toward the left until the signals become equal. When the amplitude of each signal is proportional to Z, the antenna is said to be on target.

The principles of operation of the 2-lobe system, as used in aviation fire control, also apply to the 4-lobe system which determines both azimuth and elevation angular information.

It may be noted that there is some loss in maximum range when the target is centered between the beams. This occurs only during track modes, and maximum range in search

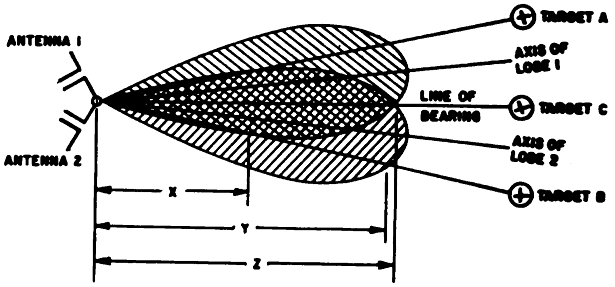

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Figure 6-7.—Double lobe pattern.

mode is unaffected. Since ranges involved in track modes are usually less than in search, some loss in maximum can be tolerated.

TYPES OF ANTENNAS

There are many different types of antennas and antenna systems employed in the field of airborne radar. However, in this manual only those peculiar to airborne fire control radar are given consideration. There are essentially two basic types of antennas employed or used in the specialized field of aviation fire control. One type is composed basically of one element, a radiating device; the other is composed primarily of two elements, a radiating element and a reflector.

Essentially an open ended waveguide can be used to produce directional radiation. Two problems which occur are (1) how to effectively match the waveguide to free space; and (2) how to achieve a narrow beam of radiation. The radiation pattern of an open ended waveguide is broad in both the vertical and horizontal planes. It is also an inefficient system because of the mismatch between the waveguide and free space.

COSECANT-SQUARED REFLECTORS

The cosecant-squared reflector is a modified version of the parabolic reflector which is discussed in Basic Electronics. Because of the variety of the applications of radar, widely different requirements must be met by different antennas. Antennas designed to produce special polarization effects or pattern shapes may differ great from those previously described. Airborne radar sets that are designed to scan a large area require a special beam shape.

This beam should be narrow in the horizontal plane, but broad in the vertical plane (fig. 6-8). In addition, the particular area to be scanned must not be illuminiated uniformly by the radar beam. Instead, the objects near the aircraft should be illuminated with less power than those farther away in the same sector, because echo signals from nearby objects will be strong due to their closeness to the aircraft. On the other hand, a greater amount of power should fall on more distant objects in this sector since they would normally produce the weakest echoes. Thus, the radiated fields of the beam should increase in strength at the greater distances. This type of pattern is employed in radar bombing equipment. Figure 6-8 (A) shows some trigonometrical relationships of this situation.

If the aircraft is at point A in figure 6-8 (A) and the target is at point B, the slant range r (straight-line distance from A to B) can be represented in terms of the aircraft altitude h and the angle of depression (θ) of the target as seen from the aircraft. This is represented by:

$$\frac{h}{r} = \sin\theta\,;\; r = \frac{h}{\sin\theta}\,;\; r = h\csc\theta$$

Thus the slant range is proportional to the cosecant of θ.

An antenna has been designed so that the field intensity pattern is also proportional to the cosecant θ. This antenna radiates a uniform electric field which causes the echo response of a nearby target to be approximately equal to that of a distant target having the same radar cross section (reflectivity). The equality of response is based on the concept of power density. Research has shown that power density is proportional to the square of field intensity. This particular antenna, therefore, produces an electric field whose power density is proportional to the square of cosecant θ.

Recalling from a review of Basic Electronics that RF signal strength is inversely proportional to the square of the distance from the source, note that a balance of signal loss against signal gain is utilized in this antenna. As the slant range r (fig. 6-8 (A)) increases, θ decreases and csc θ increases. The signal strength (power density) is inversely proportional to the square of h csc θ because the wave is RF energy; at the same time, the signal strength is directly proportional to the square of csc θ because of the antenna design. (Assume that h is constant.) The result is a net change of zero (theoretically) in the signal strength up to the maximum range of the transmitter. The antenna which produces this result is called the cosecant-squared antenna.

Figure 6-8 (B) shows the special paraboloid reflector in which the top portion is bent forward to produce the cosecant-squared pattern; also shown is the pattern itself. Notice that this antenna produces a field of constant signal strength (bounded by the dotted line at ground level (line XY)) over a broad range of values of θ

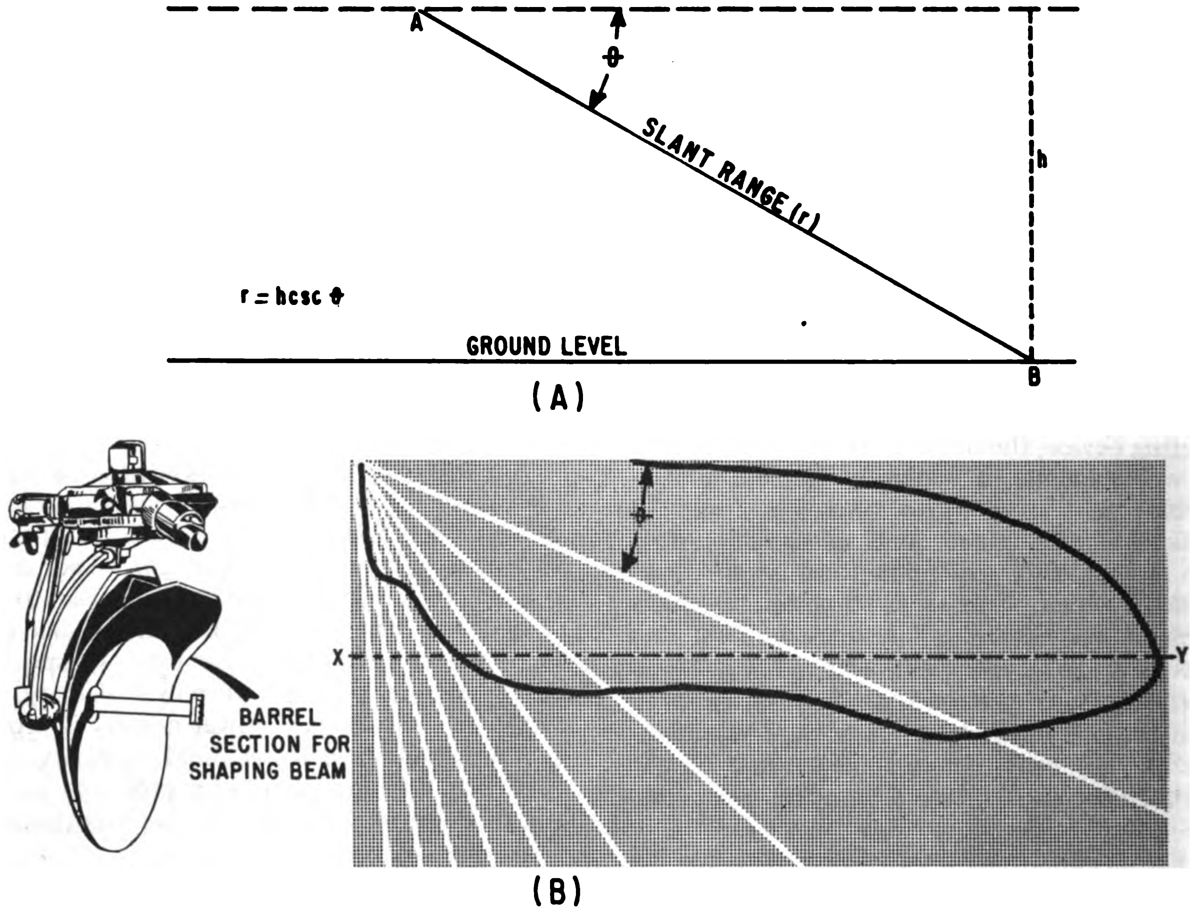

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Figure 6-8.—Cosecant-squared antenna and pattern.

This same type of antenna is also used (in an inverted position) on the land based and shipboard systems for obtaining equal indications from aircraft at equal altitudes but different ranges.

ARRAY ANTENNAS

A number of individual radiating elements suitably spaced with respect to one another is called an array antenna. The signals applied to each of these elements are controlled in amplitude and phase to obtain the desired radiation pattern from the combined action of all the elements. In an array antenna, the elements may be dipoles, waveguide horns, or any other type of antenna. For an array to exist, it must consist of two or more elements and the maximum number of elements is limited only by its application.

The array antenna differs from the lens and reflector. The lens and reflector apply the proper phase relationship to the wavefronts after it is radiated by the point-source feed. The shape of the wavefront on leaving the feedhorn is spherical. The action of the lens or reflector converts it into a plane wavefront. In the array antenna, before the signal is radiated the proper phase shifts are applied to the signal in the transmission lines.

The position of the main beam is determined by the relative phases between the elements. If the individual phases are fixed, the antenna radiation pattern is also fixed. Control of the beam formed by an array can be accomplished either mechanically, by moving the entire array antenna structure, or electronically, by varying the phase relationship between the elements of the array.

Two common forms of antenna arrays are the linear array and planar array. A linear array has a number of elements arranged in a straight line in one dimension. A planar array is a two-dimensional display of elements arranged to lie in a plane.

The two-dimensional planar array (figure 6-9) is fundamentally the most versatile of all radar antennas. A rectangular aperture can produce a fan beam, and a square or circular aperture will produce a pencil beam. Also many search and/or tracking beams can be made to be simultaneously generated with the same aperture. This technique is used in the track while scan radar, which is discussed later in this chapter.

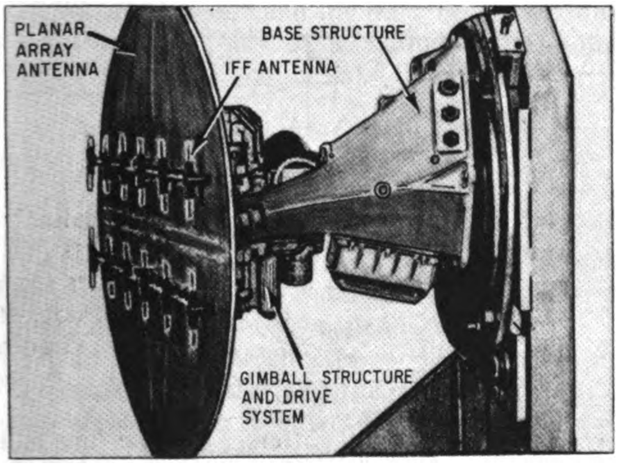

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Figure 6-9.--Two-dimensional planar array antenna.

The planar array antenna group used in the F-14 aircraft (fig. 6-9) is composed of an antenna, microwave circuitry, antenna servos, and a hydraulic power supply. The microwave circuitry couples and processes the transmitted and received RF energy. The antenna servos generate hydraulic drive signals and together with the hydraulic power supply drives the antenna.

The planar array radiating panel consists of a sheet of parallel waveguides that radiate or receive energy by shunt element slots cut in the broad wall. The interslot spacing is 0.7 free space wavelength to optimize the radiation pattern and gain characteristics. The width of the radiating waveguide is chosen so that the slots are spaced 0.5 wavelength apart to achieve proper in phase illumination. Several adjacent radiating waveguides are connected by a waveguide, which in turn has a single RF energy feed point. These waveguides comprise a module, the size of which is determined by geometrical considerations, but must be kept small for large bandwidth antennas.

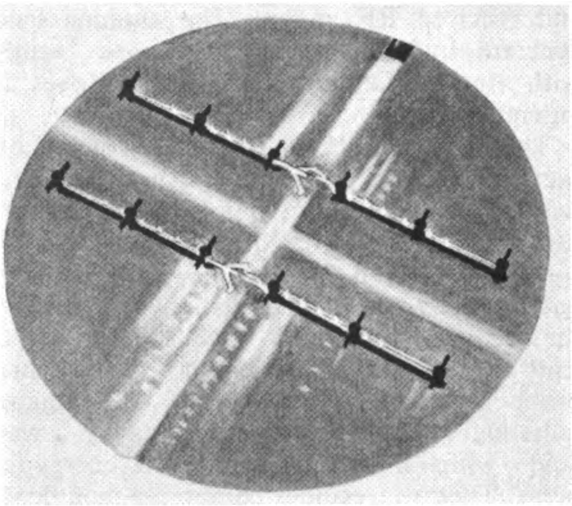
The corporate feed of the planar array distributes energy to (on transmission) or collects energy from (on reception) the various modules in each quadrant. The structure consists of thin walled sections of waveguides and H-plane power dividers (tees) arranged to provide a single input and 19 outputs per quadrant on transmission. Each output is interfaced with the input port of a module and therefore provides for the RF illumination of a small section of the overall antenna aperture.

To obtain uniform phase illumination for the aperture distribution desired, the electrical lines from the input to the corporate feed to each module are designed to have equal lengths. To obtain the desired amplitude illumination, the power division ratios of the tees are designed such that the proper amount of input power is fed to each of the several output ports. The power required at the output ports is, in turn, determined by the number of radiating slots to be fed in that module and by the position of the module in the array.

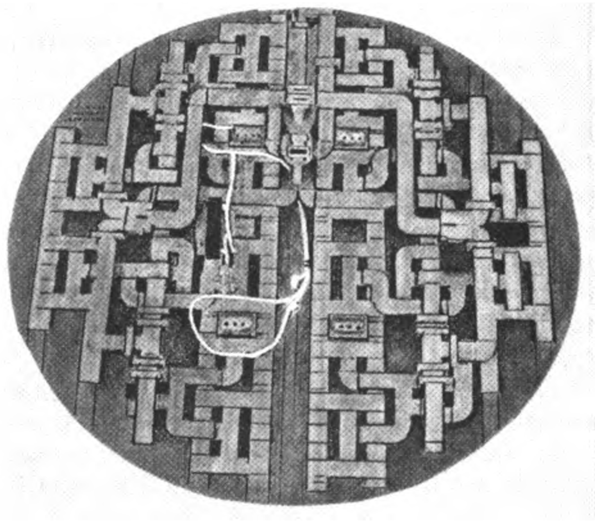
Front and rear view photographs of the planar array are shown in figure 6-10. The separate elements of the planar array (i.e., the radiating waveguide sheet, the feedguides, and the corporate feed assemblies) are assembled utilizing conductive and structural adhesives. The conductive adhesives are required to assure proper RF coupling between the sections without any RF leakage. Since the only suitable commercial conductive adhesives use silver particles as the conductive medium, an aluminum filled conductive adhesive was developed and is used in fabrication of the planar array. In this manner, the possibility of corrosion caused by the galvanic potential between dissimilar metals is substantially reduced.

A schematic of the planar array sum and difference network is shown in figure 6-11. During transmission periods, RF energy is introduced at the sum port and distributed equally in amplitude and phase to the four quadrants.

On reception, the process is reversed and a signal is received at the sum port. For plane wave signals arriving from off boresight, however, phase differences occur between the signals at the ports of the four quadrants. These phase differences are used in phase monopulse processing. The vector processing of these signals in



(A) FRONT VIEW



(B) REAR VIEW

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Figure 6-10.—Planar array.

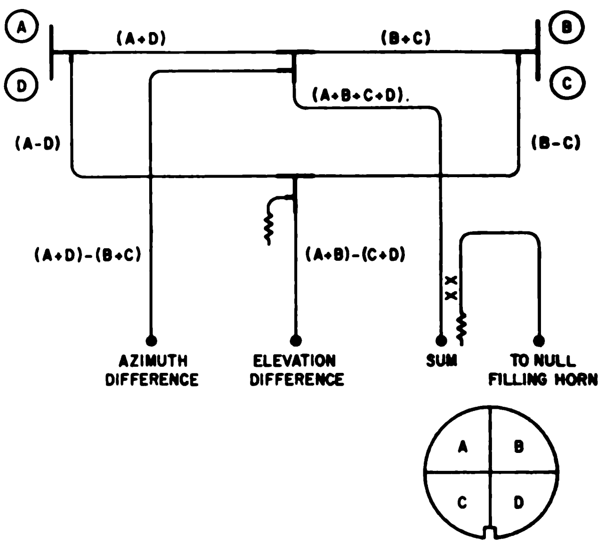

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Figure 6-11.—Planar array, sum and difference schematic.

the sum and difference network not only produces an additive sum, but also a differential sum (difference signal) in each of the two principal planes. The amplitude and phase of the difference signals relative to that of the sum signal contain the information required for angle tracking.

ANTENNA APPLICATIONS

The purpose of an airborne fire control radar system is to supply to a compute (human or electronic) accurate range and pointing angle (directional) information concerning a target for use in the firing of the aircraft's armament. While precise measurement of the range can be made by timing the radar echo, the pointing accuracy of a simple radar can be basically no better than the beam width of the antenna. The antenna beam width is approximately λ/D (radius, where λ is the wavelength of the radiation and D is the antenna width or, for a paraboloid, the diameter). As the beam width becomes narrower, the pointing angle accuracy will improve. Since a beam width of several degrees is typical of airborne fire control radar antennas, new design features are required in the system to provide the desired pointing accuracy of a few milliradians (which are only one or two hundreths of the beam width). The basic method of obtaining the higher accuracy may be termed "lobe comparison," and the numerous variations of the method may be classified as "simultaneous" and "time sequential."

SIMULTANEOUS LOBE COMPARISON SYSTEMS (MONOPULSE)

In the simultaneous lobe comparison system, complete target position information is obtained on each pulse of the radar set. For this reason the system is commonly called monopulse.

From the target echo the monopulse antenna derives signals which give the range of the target and its direction relative to the axis of the antenna. There are three waveguide terminals, one for the transmit and range signal reception, and one each for azimuth and elevation error signal reception (fig. 6-12). The RF signals which appear at these three terminals are used to provide the d-c pointing error voltages. The signals picked up by the feed apertures are combined in such a manner that their sums and differences are obtained. Two types of radiation patterns result in each plane, a sum pattern (fig. 6-13) and a difference pattern (fig. 6-14). The sum signal is used for search operations and gives the range of the target. The sum pattern, obtained by the inphase addition of the echo signal received by the two apertures in one plane, is characterized by a main lobe of considerable directivity along the antenna axis. The difference pattern for any one plane is obtained from the difference between the echo signal as received by each of the apertures in that plane. From these signals the azimuth and elevation error signals are obtained by comparison of the difference signals with the sum signal in each plane. The difference pattern has two main lobes and a null on axis. The main lobes are symmetrical and equal for a difference pattern plotted in power; however, the fields associated with the two lobes are 180° out of phase; and the RF voltage appearing at the antenna error channel terminals varies with angle, as in figure 6-15. (This description assumes perfect symmetry in the antenna.)

The nonlinear response of the radar receiver with its automatic gain control modifies the error characteristic so that the final d-c error signal which controls the antenna pointing servos varies somewhat with pointing error (fig. 6-16). The pointing accuracy of the system is dependent on the steepness of the overall characteristic near zero. If the noise in the system has an amplitude as shown in figure 6-16, small error signals will be masked by the noise; and the antenna will point erratically between angles $+\beta$ and $-\beta$. A steeper characteristic decreases this error. The steepness of the overall characteristic is proportional to the slope of the antenna difference voltage characteristic, and it is desirable to design the antenna to maximize this slope. The error characteristic is an intrinsic feature of the antenna and depends on the aperture illumination.

The relative level of the noise (fig. 6-16) depends on the signal to noise ratio, so that the signal to noise ratio in the final error signal output determines the pointing accuracy of the system. The overall signal to noise ratio is determined by the RF signal at the mixer, and this signal depends on both the antenna trans-

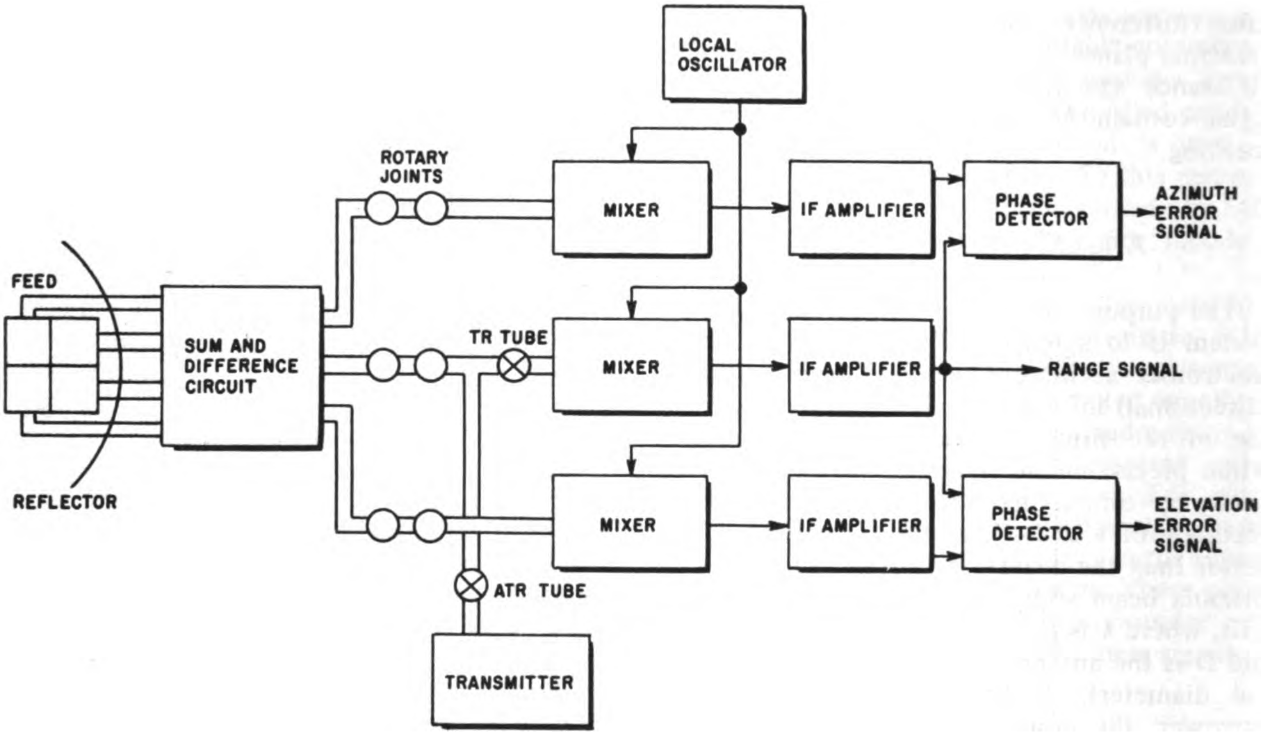

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Figure 6-12.—Three-channel monopulse radar system.

mitting and the error receiving characteristics. The received wave is a reflection of the transmitted wave, and is proportional to the gain of the antenna transmit channel. Thus, a true measure of the antenna error sensitivity must be a function not only of the slope of the antenna error voltage characteristic, but also of the antenna transmit channel gain.

Monopulse systems are usually classified as phase comparison, amplitude comparison, or phase amplitude comparison, depending on the characteristics of the antenna.

Phase Comparison System

In the phase comparison type, there are always two or more apertures in each plane that are fed independently. The target echoes picked up by the two apertures are equal in amplitude because the apertures are oriented together; but when the target is not on the axis of the antenna, the echoes picked up by the apertures differ in phase, since one aperture of the antenna is closer to the target than the other.

Amplitude Comparison System

In this monopulse system, at least two components of the feed aperture are alined in each plane and are generally smaller than those of the phase comparison type (since there is no need for size or geometric separation to pick up several phases of the incident wave). The target echo excites each aperture differently, and pointing information is derived from the resulting amplitude difference.

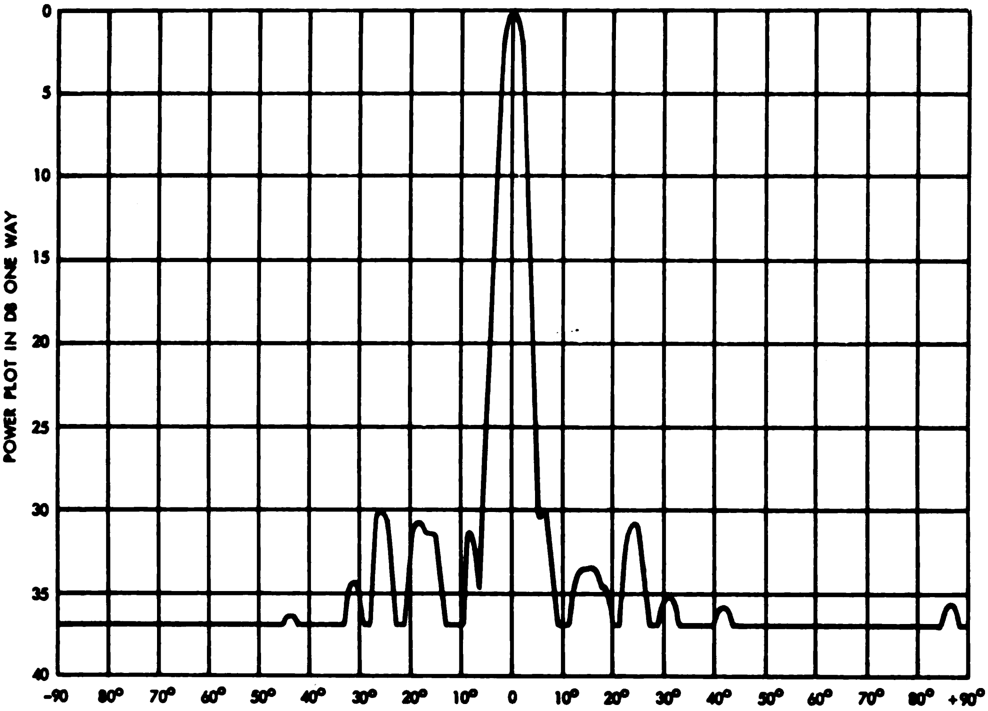

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Figure 6-13.—Typical sum radiation pattern of monopulse antenna.

Phase Amplitude Comparison System

In this system (a combination of the other two types), error signals are obtained by phase comparison in one plane and by amplitude comparison in the other.

MONOPULSE SYSTEM ERRORS

In any of the monopulse antenna systems, pointing errors can arise in two distinct ways. Phase or amplitude discrepancies in the received signals, which result from asymmetries in the feed structure or from radome refraction, give rise to pointing errors. A second contribution to the pointing error arises from the combined effects of the radome error and the asymmetries and of phase errors between the parallel receiver channels which are required in a monopulse system. Signal errors in phase or amplitude are always present to some degree, since the feed structure and the radome cannot be perfect. Similarly, phase discrepancies between receiver channels will generally be present. For satisfactory system performance, however, it is mandatory that both sources of pointing error be minimized; in fact, the design of IF amplifiers with satisfactory phase characteristics over a large dynamic range constitutes one of the major problems in a monopulse system.

A constant phase distortion causes the antenna pointing angle to deviate a fixed distance as long as the frequency is constant; however, at a constant frequency, variations will occur in the errors introduced by amplitude distortions in combination with phase errors between receiver channels.

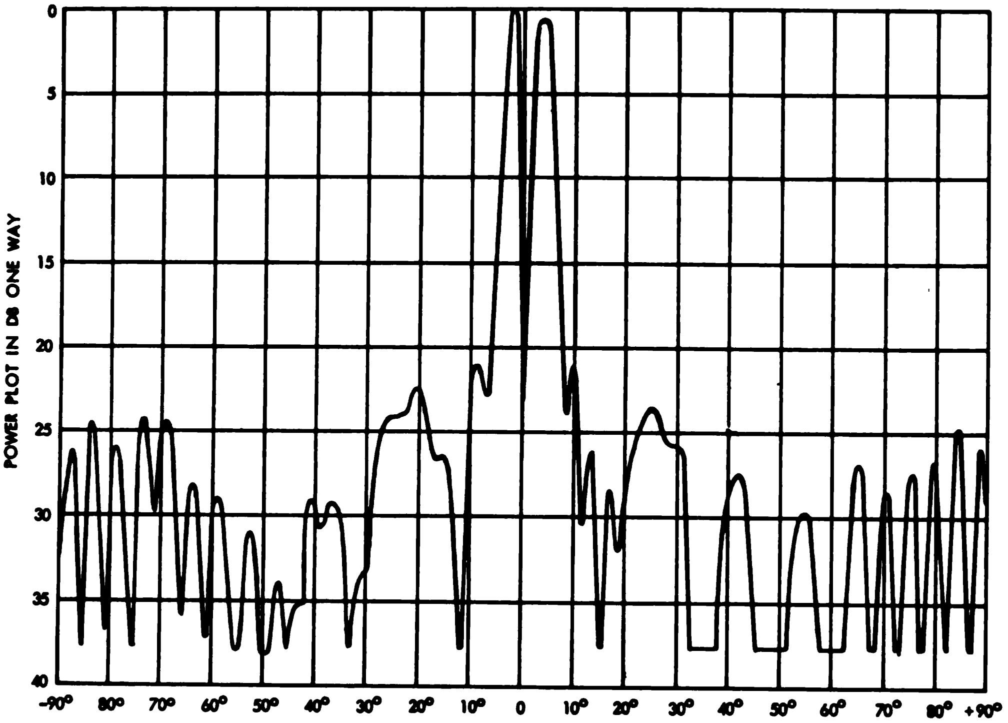

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Figure 6-14.—Typical difference radiation pattern of monopulse antenna.

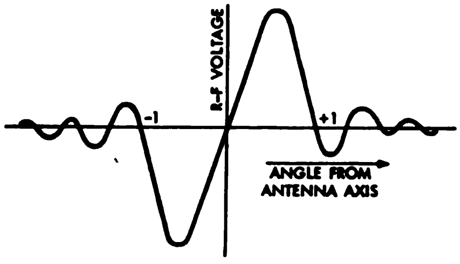

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Figure 6-15.—RF voltage at error terminal of antenna.

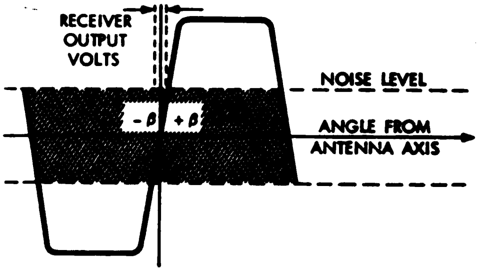

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Figure 6-16.—D-c error voltage at servo input.

Some shift in itself is not detrimental (as long as the frequency is constant), since it merely defines a new pointing axis. The position of the new axis, however, varies with frequency, and it is the shift of the pointing axis with frequency which is important. The phase error between feeds may result from structural asymmetries in the feed, or it can result from radome effects as well. Since the phase errors caused by the radome vary as the antenna scans, a variable shift in pointing axis then results, even with a fixed frequency. The major sources of error for both phase and amplitude comparison monopulse systems are in the feed system as follows:

1. For the phase comparison system the primary errors are phase errors, and secondary errors are amplitude errors (in front of the sum and difference circuits).
2. In the amplitude comparison systems, the primary errors are amplitude errors and secondary errors are phase errors.
3. Both systems experience phase errors between receiver channels.

TIME SEQUENTIAL LOBE COMPARISON SYSTEMS

The time sequential classification includes conical scan and sequential lobing systems. Conical scanning was discussed previously and is compared to sequential lobing in the following paragraphs.

A time sequential radar system which provides only four positions in rotation is the "sequential lobing" type (fig. 6-17). The sequential lobing antenna has four feed apertures. By means of waveguide switches, these four apertures may be used individually in sequence to provide without motion the same result as conical scan but at much higher scanning speeds than are possible mechanically. The construction of some sequential lobe comparison systems inherently provides a further advantage over conical scan–all four apertures transmit simultaneously; only one receives at a time. In this way the peak of the transmitted beam is on the crossover axis, giving a larger target reflection than in the conical scan system, in which the beam peak is displaced from the crossover axis.

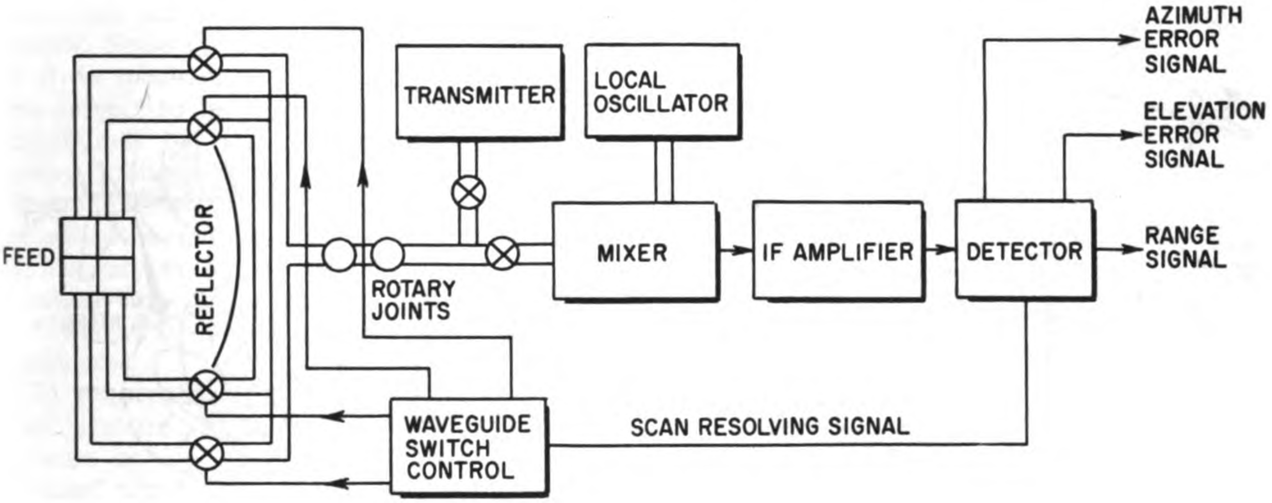

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Figure 6-17.—Sequential lobing radar system.

COMPARISON OF MONOPULSE WITH TIME SEQUENTIAL SYSTEMS

The essential characteristic of both the conical scan and sequential lobing systems is that they measure echoes received at different times. (See fig. 6-18.) The monopulse systems, on the other hand, derive all range and pointing information from each single pulse echo (figs. 6-19 and 6-20). The classification of fire control antennas as simultaneous lobe comparison or time sequential lobe comparison is made because a significant advantage of monopulse appears in this connection. Since time sequential lobing entails comparison of two echoes separated in time, changes in the reflective properties (scintillation) of the target or fluctuation in transmitted power can cause false error signals. vulnerable to certain types of jamming. The higher scan speed obtainable, by sequential lobing with waveguide switches instead of mechanical motion, reduces but does not eliminate these spurious error signals. The mono-

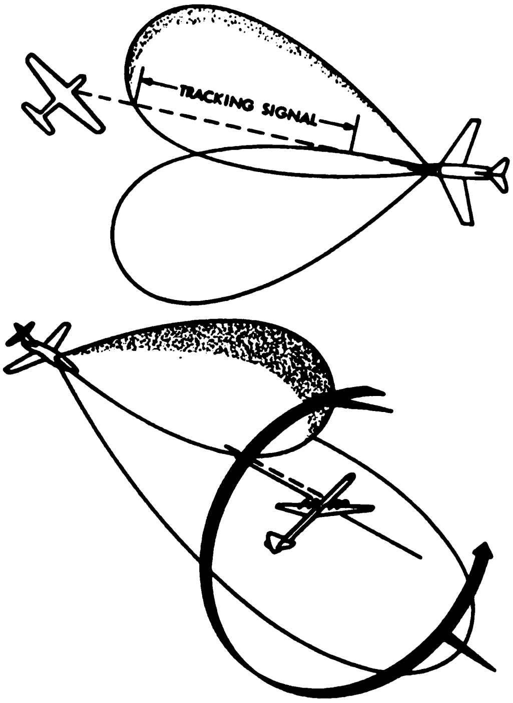

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Figure 6-18.—Typical fire control antenna beam—conical scan.

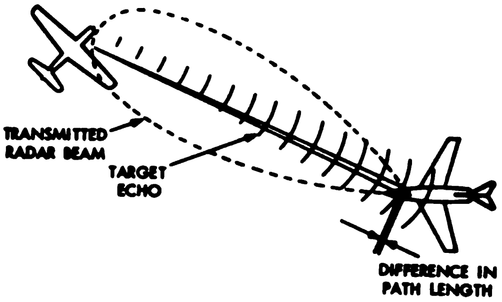

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Figure 6-19.—Typical fire control antenna beam—phase comparison monopulse.

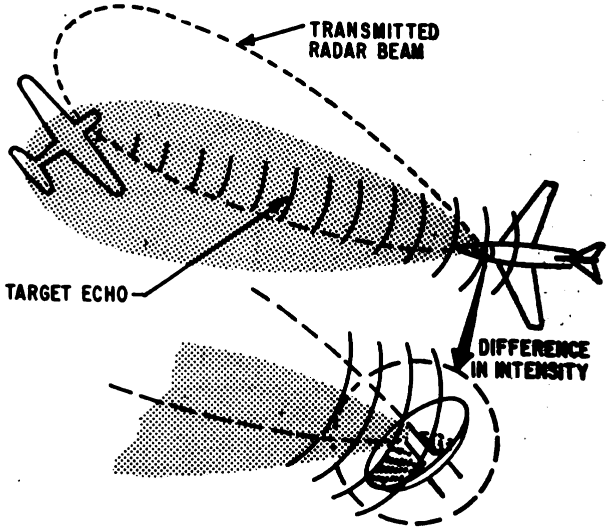

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Figure 6-20.—Typical fire control antenna beam—amplitude comparison monopulse.

pulse, deriving complete information from each pulse, is not susceptible to these effects.

An advantage monopulse enjoys over conical scan, although not necessarily over sequential lobing, is a greater overall angular sensitivity, because the target is tracked at the peak of the transmitted beam. In conical scan, the target is tracked at the beam crossover, which is usually near the half power point. The voltage sensitivity is essentially equal for both monopulse and conical scan antennas, but the overall angular sensitivity is less for the conical scan because of the weaker echo. The sequential lobing antenna can be designed to track the target at the peak of the transmitted beam and can avoid the power loss inherent in the conical scan. However, with a sequential lobing system, the RF noise produced in the received signal by existing lobe switching tubes is a major disadvantage.

In a conical scan antenna, input impedance varies with rotation of the scanning mechanism. The changing load presented to the magnetron causes fluctuations both in frequency and in power. A unilateral device, such as a ferrite gyrator, is necessary to overcome this problem. The input impedance of a monopulse antenna remains essentially constant, since there are no moving elements except the rotary joints.

Mechanically, the monopulse antenna is somewhat more complex than the conical scan type, but there are no moving parts in the antenna proper. Since the antenna feed has no bearings or drive mechanisms, the monopulse system is less subject to mechanical breakdown. Pressurization may be easier. However, the additional rotary joints which are necessary if receiver components are not mounted on the antenna are an added complexity. Although monopulse antennas vary in weight from type to type, they compare favorably with the conical scan when the weight of the spin motor and resolver is considered.

In sequential lobe comparison and conical scan systems, the pointing error information appears as an amplitude modulation of the received signal. Only one channel, involving one rotary joint in each gimbal axis, one mixer, and one IF amplifier, is necessary to carry this information. In a sense this single channel is time-shared. The monopulse system, on the other hand, deriving complete pointing information from each pulse echo, cannot time-share one channel, but requires two or three. The multiplicity of receiver components and rotary joints adds weight and complexity and tends to decrease the electrical reliability. The additional rotary joints may be avoided by mounting some receiver components on the antenna, although this arrangement adds inertia to the antenna and requires the use of flexible cables. The decision whether to suffer the additional rotary joints or to avoid them by placing receiver components on the antenna is an involved one which must be reached for each particular application.

TRACK WHILE SCAN

The use of the digital computer has greatly increased the versatility of the aviation fire control systems. With the use of a digital computer, interpolative tracking is possible. Interpolative tracking provides for the tracking of more than one target with the maximum targets being limited to the capacity of the digital computer. This technique is called track while scan.

During the track while scan mode, a search pattern may be used as shown in figure 6-21. In

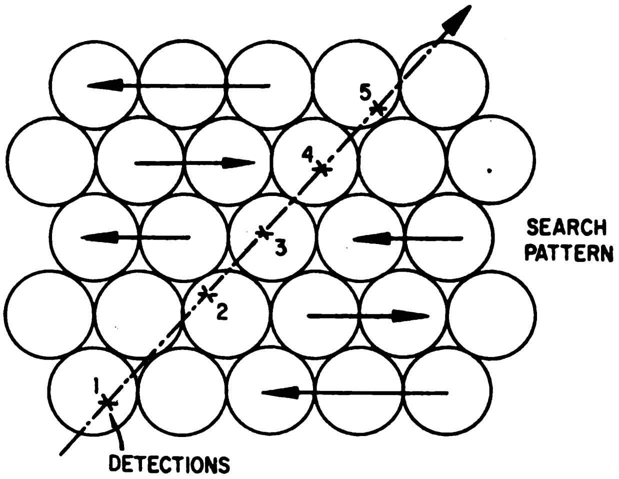

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Figure 6-21.—Track while scan search pattern.

this pattern each circle represents a monopulse cluster. Any detections that occur off the boresight or center of a monopulse cluster result in angle-deviated monopulse signals. These radar observations of range, range rate, elevation, and azimuth of targets within the scan pattern must be sorted into groups of observations that presumably have been obtained from the same target. A track is a set of observations that have been so grouped and the sorting process applies new observations with the track. Past observations of a target are smoothed and used to predict its location at the time of the next observation.

As previously mentioned, the digital computer determines the number of targets that can be tracked, which may be as high as 20. If the attacking aircraft is carrying six missiles, the track while scan radar can guide all six missiles to six different targets. The targets chosen are usually the ones that are the nearest to the attacking aircraft; however, any target that is being tracked can be attacked.

ANTENNA BORESIGHTING

PURPOSE AND METHODS

The purpose of boresighting aircraft weapon systems is to establish a relationship between the flight attitude of the aircraft, the bore axes of the armament, and the axis along which the sighting is projected. The theory of boresighting involves analyzing pertinent ballistics and mechanical data in establishing the relationship between the sight line of the aiming device and the trajectory of the projectile being fired or launched in order to predict its mean point of impact at predetermined ranges. No weapons system can do its job accurately unless it is properly alined with the weapon with which it is used. Thus the weapon system and weapon must be made to function together. This technique of making them function together is called boresighting.

The primary reference of boresighting of the entire aircraft is the zero-zero radar axis. This is the line in space along which the radar antenna will point when tracking a target with zero azimuth and elevation gimbal angles.

The first method of boresight is called full boresight and provides for a complete RF and optical boresight, as a result of which the state of alinement of the radar axis and optical axis is determined. The Maintenance Instruction Manual should be consulted for the step by step procedure.

The second method is called radar silence boresight. It is the same as the first except that a telescope fixture is used as the only reference. This procedure can be used whenever it is impossible to radiate, or sufficient time does not exist for the full procedure.

The third method, called fast boresight, is only for use with the director portion of the aircraft weapons system. This method can be used only when the aircraft has been boresighted previously, using the full procedure with a given antenna. This method can then be used to establish the electrical boresight of the director.

The boresighting procedure for purposes of this manual is carried out in two phases—electrical boresighting and harmonization. Electrical boresighting is the procedure used in bringing the radar antenna's RF axis into a parallel relationship with its optical axis. This procedure must be carried out before the harmonization procedure.

Harmonization is the procedure for bringing the radar antenna's optical axis into a parallel relationship with the aircraft armament datum line. Harmonization also extends to the adjustment of the guns and optical sight unit.

Electrical boresighting will require that RF energy be radiated. However, in most aviation fire control radars, satisfactory harmonization can be accomplished without radiation, provided the antenna's optical axis is in proper agreement with the RF axis of the antenna. Once accomplished, the electrical boresight should remain valid as long as no portion of the antenna structure is damaged, replaced, repaired, or the adjustments disturbed.

APPLICATIONS OF BORESIGHTING

Short Range Boresighting

Short range boresighting is used where space is at a premium such as on an aircraft carrier. In past years short range boresighting was not considered the best method and was only used when necessary

Modern aircraft can now be accurately boresighted utilizing the short range boresight equipment provided by the aircraft manufacturer. Figure 6-22 shows a short range boresight kit installed on an aircraft. The equipment is installed on the structure of the aircraft which eliminates the need of jacking or leveling. With the boresight fixture correctly installed on

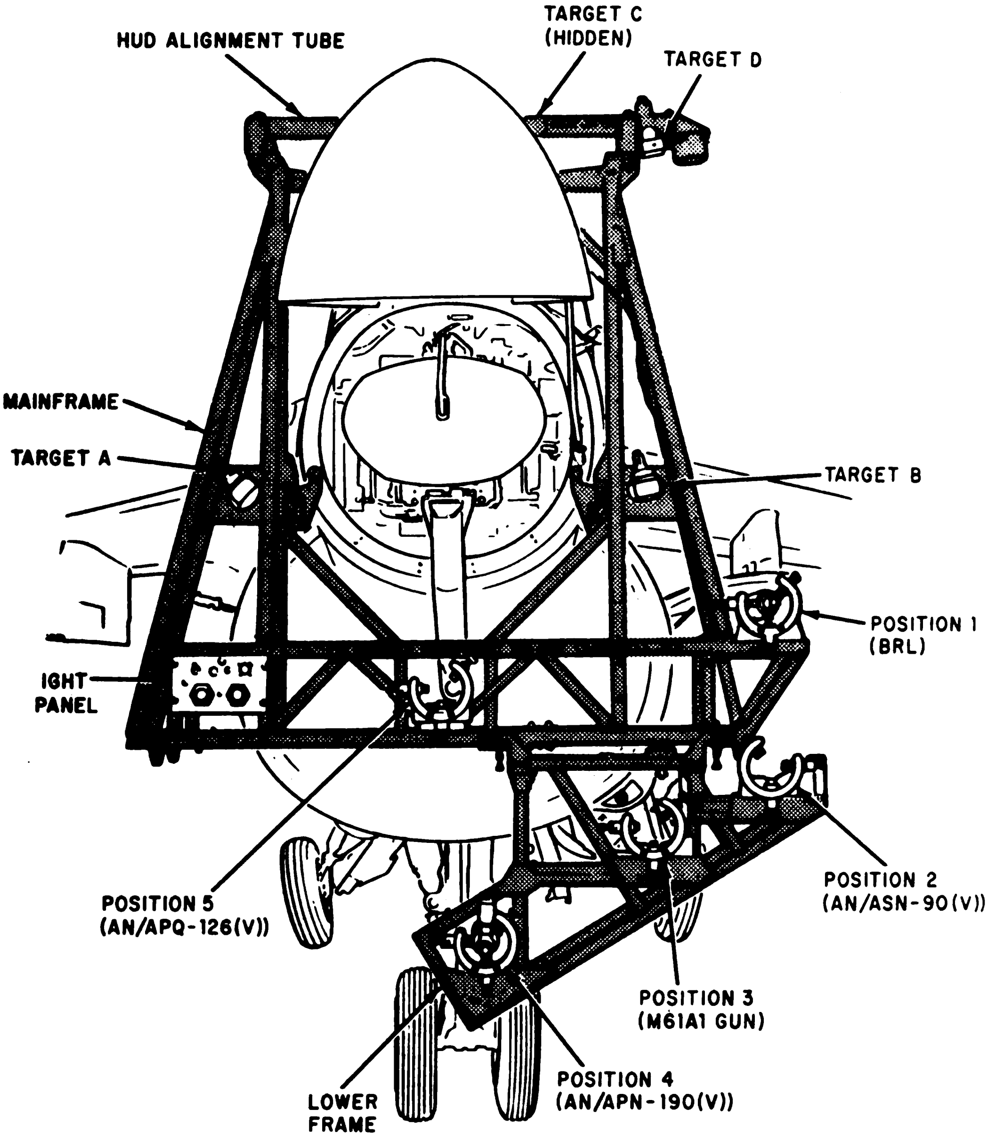

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Figure 6-22.—Short range boresighting equipment.

the aircraft, the AQ can boresight the radar, the AO can boresight the guns, and the AT can aline the navigation equipment.

The equipment is considered to be a precision instrument and must be calibrated by a Naval Air Rework Facility (NARF). Care must be exercised to avoid dropping or bumping the equipment to maintain its calibration.

Each type of aircraft is provided with its own short range boresighting equipment; procedures for installation and alinement of the aircraft equipment are contained in the Maintenance Instruction Manual for that particular type of aircraft.

Far Field Antenna Boresighting

In the far field antenna boresighting method, the antenna under test is boresighted to a source feedhorn by receiving radiated energy that is being transmitted by the source feedhorn. For these antennas, a far field antenna test range normally requires at least 50 feet between the radar antenna under test and the radiating antenna source. (See fig. 6-23.) The distance can be calculated using the formula

$$R \geqq \frac{2D^2}{\lambda},$$

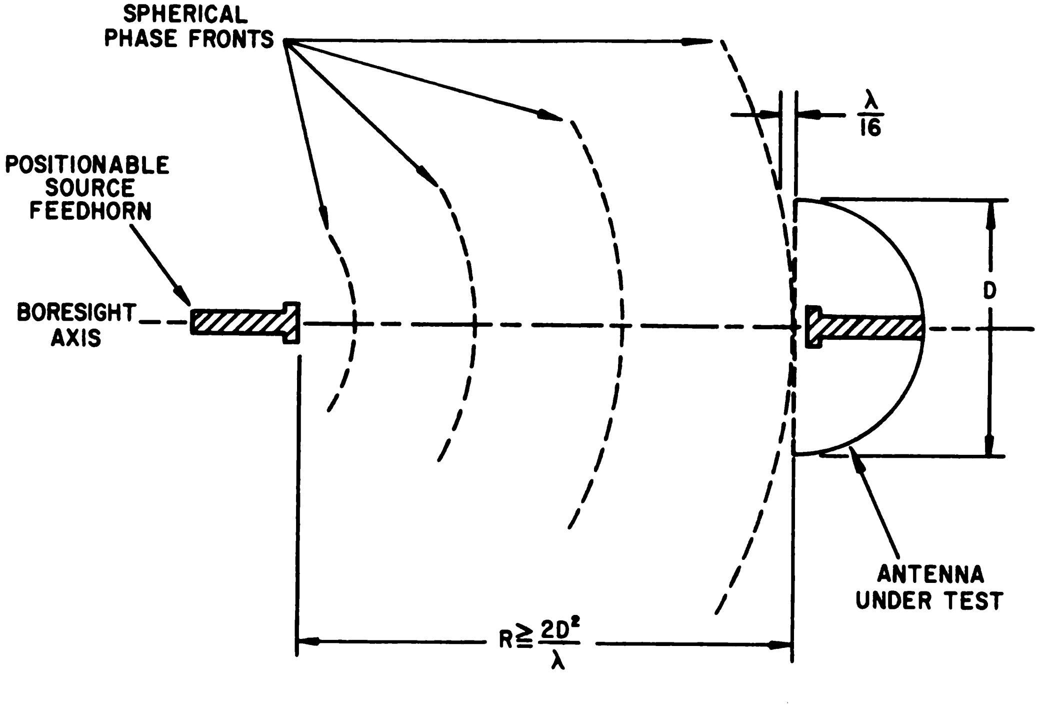
where

R = range

D = diameter

λ = wavelength.

At this distance, the wavefront deviates no more than 1/16 of a wavelength from a plane wavefront, which is the minimum deviation for accurate boresighting.



AQ.36

Figure 6-23.—Far field measurements conditions.

Antenna Boresight Test Set AN/APM-334

A test set that can simulate the electromagnetic far field antenna test range is the AN/APM-334. The test set provides a means of converting the spherical wavefronts to plane wavefronts (fig. 6-24). The spherical wavefronts incident upon the lens are retarded in phase as they are propagated through the lens, resulting in a plane wavefront emerging from the face of the lens. The separation between the antenna receiver under test and the radiating source feedhorn is reduced to approximately 4 feet.

The Test Set AN/APM-334 (fig. 6-25) is used for the radar system installed in the A-7 aircraft. It is composed of an SHF signal generator (1), an oscilloscope (2), a servo control unit (3), a signal and crystal monitor unit (4), a control and power supply unit (5), and a swing plate and utility lights section (6).

Figure 6-26 shows an antenna mounted on the AN/APM-334 test set and being boresighted. The SHF signal generator supplies the radar signal at the required frequency to the source feedhorn for transmission through the lens to the antenna receiver. At the directional coupler, a portion of the radar signal is sampled and its frequency is measured using the frequency meter and the signal monitor meter. Source feedhorn controls are used to position the source feedhorn accurately within the boresight target area of the antenna receiver. The oscilloscope is used to visually monitor signals from the antenna under test. For a complete and accurate alinement or boresight procedure for any antenna, the Maintenance Instruction Manual for the applicable aircraft should be consulted.

MICROWAVE FERRITES

Ferrites are unique because they have useful magnetic properties and are also insulators. RF

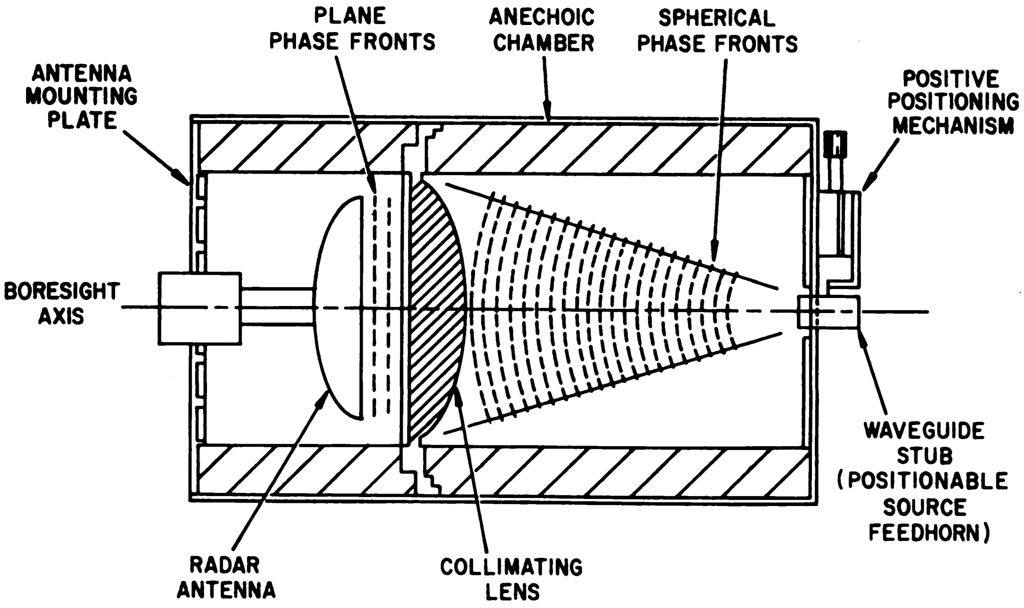


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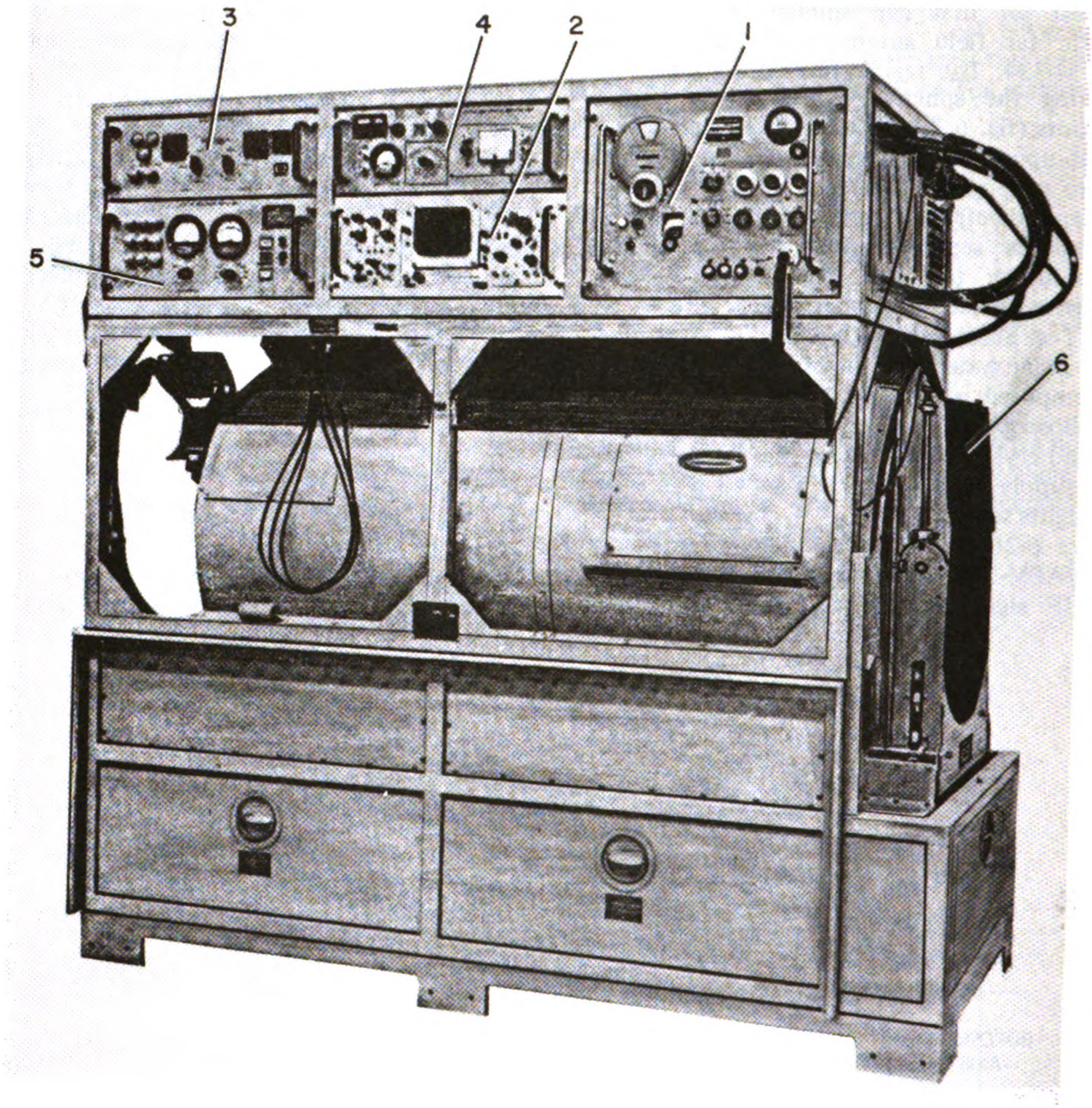
Figure 6-24.—Lens chamber assembly.



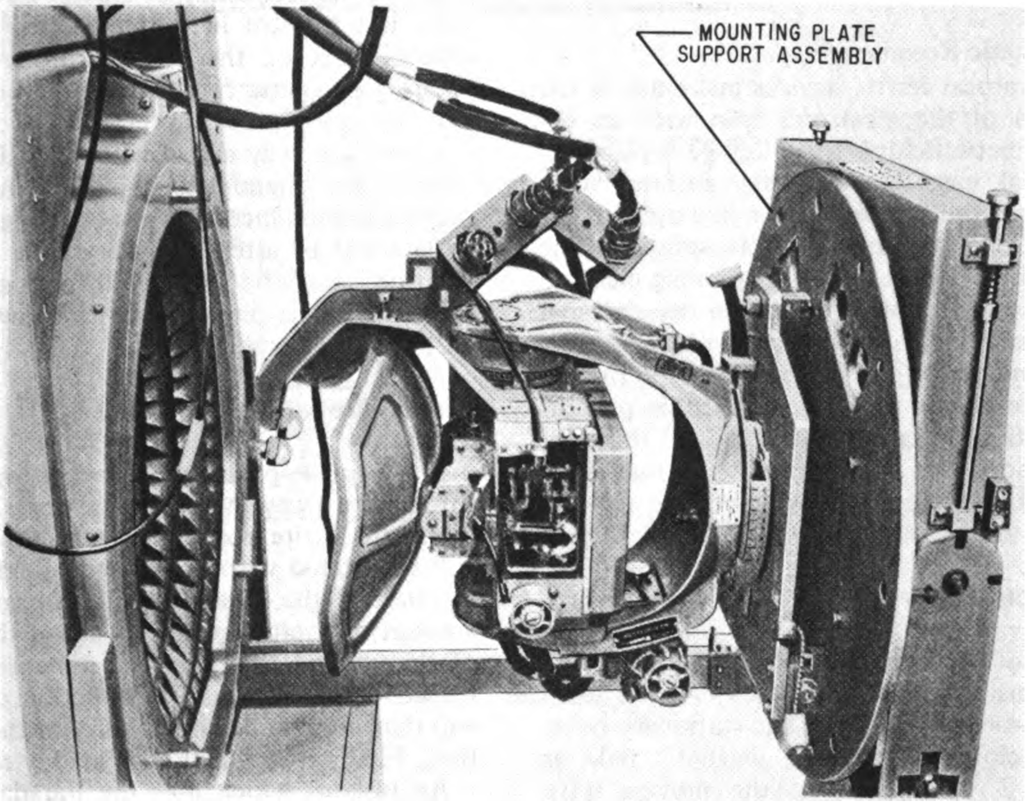
AQ.38

1. SHF signal generator.
2. Oscilloscope.
3. Servo control unit.
4. Signal and crystal monitor unit.
5. Control and power supply unit.
6. Swing plate and utility lights section.

Figure 6-25.--Antenna Boresight Test Set AN/APM-334.

fields can penetrate ferrite; this is not possible in conducting magnetic substances.

The more common ferromagnetic substances–iron, nickel, cobalt, and their alloys–are good electrical conductors; they cannot be used as magnetic materials at the higher frequencies because of eddy current losses. The ferrites are not subject to eddy currents, and even



AQ.39
Figure 6-26.–Antenna mounted on test set AN/APM-334.

though their magnetic susceptibility is much lower than that of the ordinary ferromagnetic substances, they can be and are used extensively at the higher frequencies. Ferrites with a wide range of magnetic and electrical properties can be produced.

Another class of magnetic oxides, the garnets, are used extensively as magnetic substances at high frequencies. The garnet is a rather complex oxide (compared to ferrites). The garnet crystal can fit several of the rare earths into its lattice. The rare earths have several unpaired inner electrons and therefore have strong magnetic properties. The yttrium-iron garnet is probably the most useful of the garnets at present. Certain devices employing ferrites could formerly be used only at microwave frequencies. The garnet has made it possible to use these devices at frequencies as low as UHF.

NONRECIPROCAL DEVICES

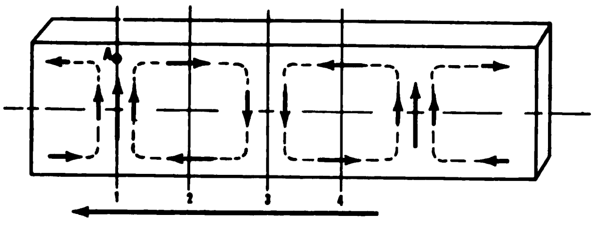
At microwave frequencies, the greatest use of ferrites is in nonreciprocal propagation devices. Nonreciprocal devices can be used to isolate a signal source from its load. A magnetron or other microwave signal source operating into a varying mismatched load (as in the case of a scanning antenna which is fed by a waveguide with rotating joints) tends toward frequency "pulling." If the reflected energy caused by mismatch is absorbed or diverted before it reaches the source, the source will see a constant load.

Ferromagnetic Resonance

Nonreciprocal ferrite devices make use of the interaction of the electron's spin with an external magnetic field. When a ferrite is placed in an external magnetic field, the atomic "magnets" within the ferrite tend to line up with the external field (i.e., the electrons' spin axes line up with the external field). A spinning electron has gyroscopic properties. When an external force attempts to change the spin axis, the electron precesses. Any gyro has a preferred or natural precession frequency which is proportional to the strength of the external field. By proper choice of ferrite and external field strength, the natural precession frequency can be made to occur at any selected microwave frequency.

An electromagnetic wave traveling down a waveguide will produce, at a point off the centerline of the guide, a rotating magnetic field. This is illustrated in figure 6-27. As the wave advances from right to left, the stationary point A sees a clockwise rotating magnetic field as points 1, 2, 3, and 4 on the moving wave pattern go past. A wave traveling from left to right will produce, at point A, a magnetic field with counterclockwise rotation.

A slab of ferrite placed off center in a waveguide, as shown in figure 6-28, will act as a one-way device at a frequency which depends on the external magnetic field strength. If the ferrite's preferred electron precession frequency matches the frequency of an RF wave traveling from left to right in the guide, the ferrite will absorb most of the energy in the wave; the rotating magnetic field as seen at point A will aid electron precession. The electrons will precess vigorously and convert the RF energy to heat. This phenomenon is known as ferromagnetic resonance. A wave traveling from right to left will be attenuated very little because its rotating magnetic field will oppose electron precession. The one-way device shown in figure 6-28 is a resonance isolator.



AQ.66
Figure 6-27.—Rotating magnetic fields in a waveguide.

Faraday Rotation

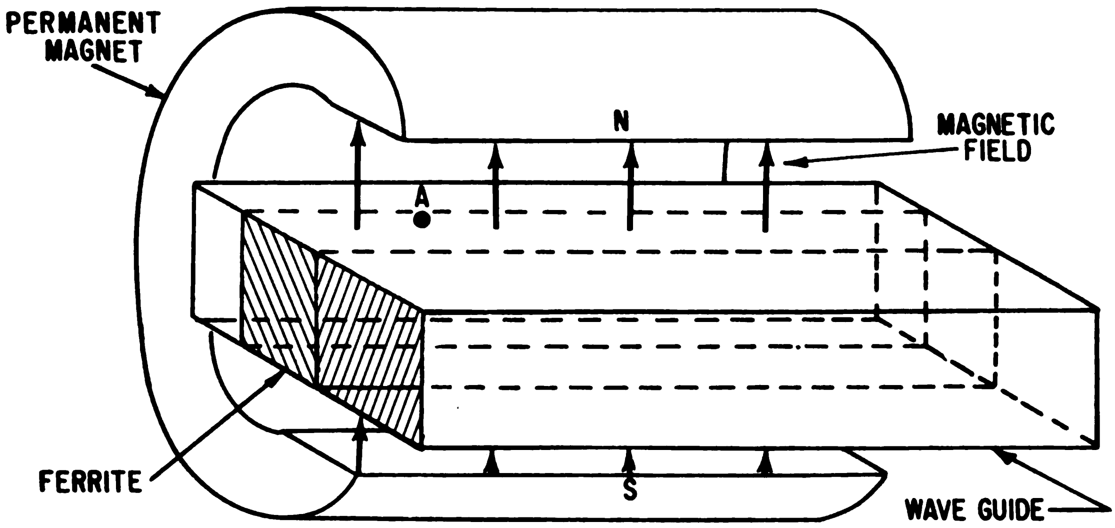
If a plane-polarized wave is propagated through a waveguide containing an axially mounted ferrite rod, the plane of polarization will be rotated when a magnetic field is applied parallel to the direction of propagation. The amount of rotation will depend on the strength of the applied field and the dimensions of the ferrite rod. The sense or direction of rotation will depend only on the polarity of the magnetic field. Figure 6-29 illustrates Faraday rotation.

An isolator which uses the Faraday effect is shown in figure 6-30. A plane-polarized wave comes down the guide and goes through a rectangular-to-round waveguide transition. As the wave passes the ferrite, its plane of polarization is rotated 45° clockwise, and it leaves through the rectangular guide. If a wave comes down the guide in the reverse direction, it will also be rotated 45° clockwise (as viewed from the left) as shown in figure 6-30 (B). The wave will be 90° from the transmission plane of the rectangular guide (the guide will be cut off for this polarization), and the wave will be reflected. Properly oriented vane type absorbers will absorb this energy without affecting waves traveling in the other direction.

In isolators designed to handle high power, the reflected wave can be coupled out to a separate power absorbing load. An isolator of this type is shown in figure 6-31.

Switches

A Faraday isolator can be modified to act as a single pole, double throw, waveguide switch. In the waveguide switch, the output end of the



AQ.67
Figure 6-28.—Resonance isolator.

device has two rectangular output guides 90° apart. Each output guide is 45° from the input guide at the other end of the device. An electromagnet supplies the external field. Switching is accomplished by reversing the direction of current flow in the electromagnet. Current in one direction causes the RF wave polarization to be rotated clockwise 45°. Electromagnetic current in the opposite direction causes the wave polarization to rotate 45° counterclockwise. In each case, only one of the output guides will accept the RF wave. Switching times of less than 1μ sec are possible. Isolation between the output guides (if they are properly terminated) is on the order of 40 db. This type of switch can be used to switch a transmitter between two antennas.

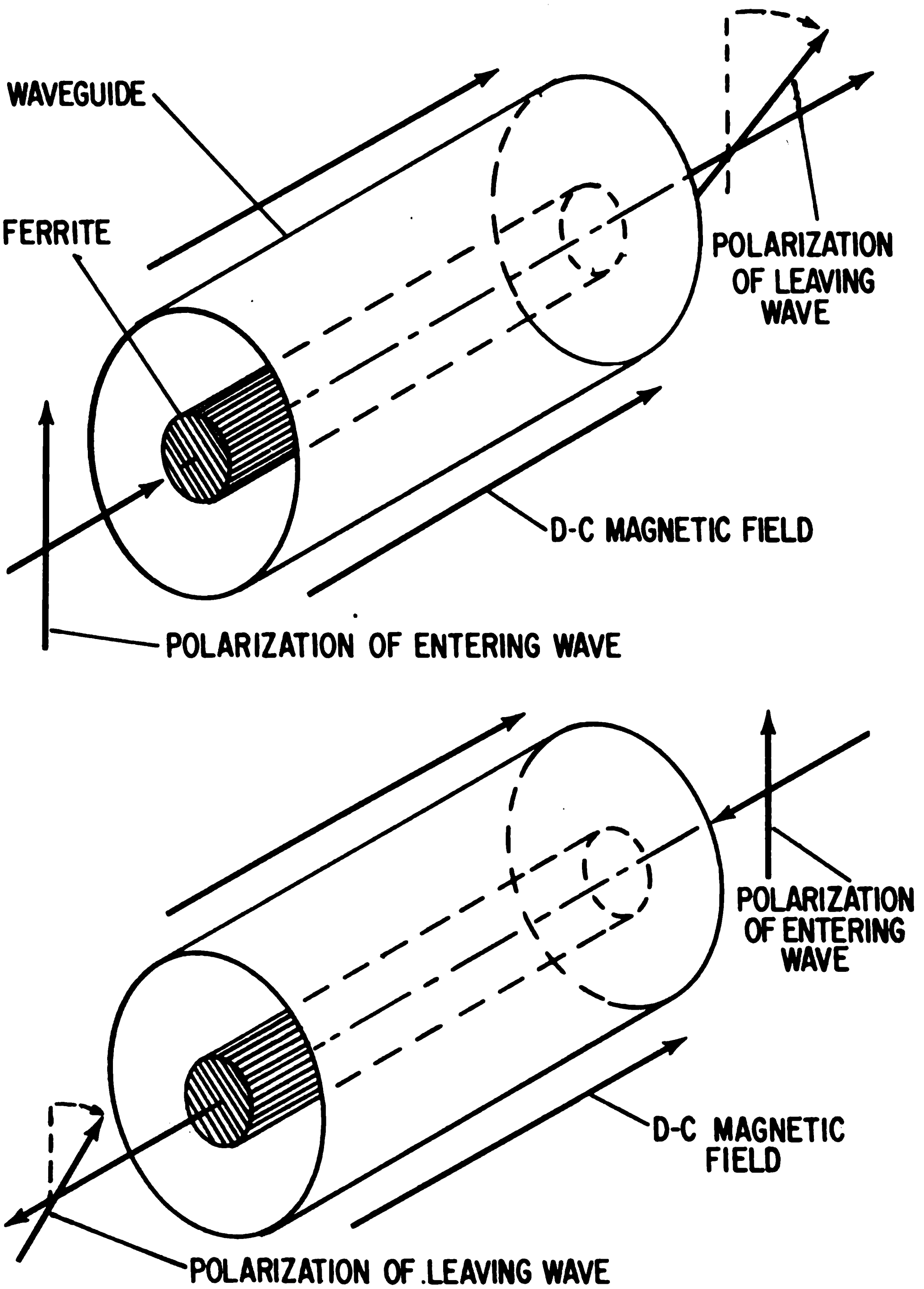
Circulators

A circulator is a device which allows one-way propagation of signals through it. It may have several input-output ports. Figure 6-32 is a schematic of a four-port circulator. The arrow shows direction of power flow within the circulator. Power entering port one leaves by port two only; power entering port two leaves by port three only, and so on. This one-way power flow between ports results from rotation of the signal polarization between ports. Each port is so oriented that it will be cut off for all signals except those which entered the port just before it. Each port, if it is properly terminated, will accept all of the power from the preceding port. Figure 6-33 shows a four-port circulator used as a radar duplexer. The load at port four absorbs any local oscillator signal from the receiver and prevents it from being radiated.

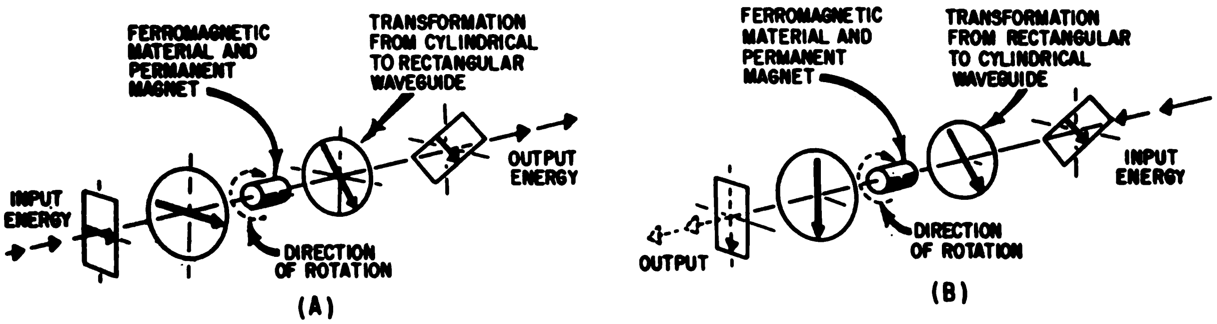
RING DUPLEXER

The hybrid ring is a type of duplexer somewhat different from those already discussed. It is capable of performing the functions of the duplexer previously discussed. In addition, it is capable of handling high power with a minimum of impedance mismatch.

The ring duplexer is a coupling device which routes the RF energy from the magnetron to the antenna, and the received signals (echoes) from the antenna to the receiver. It is a circular

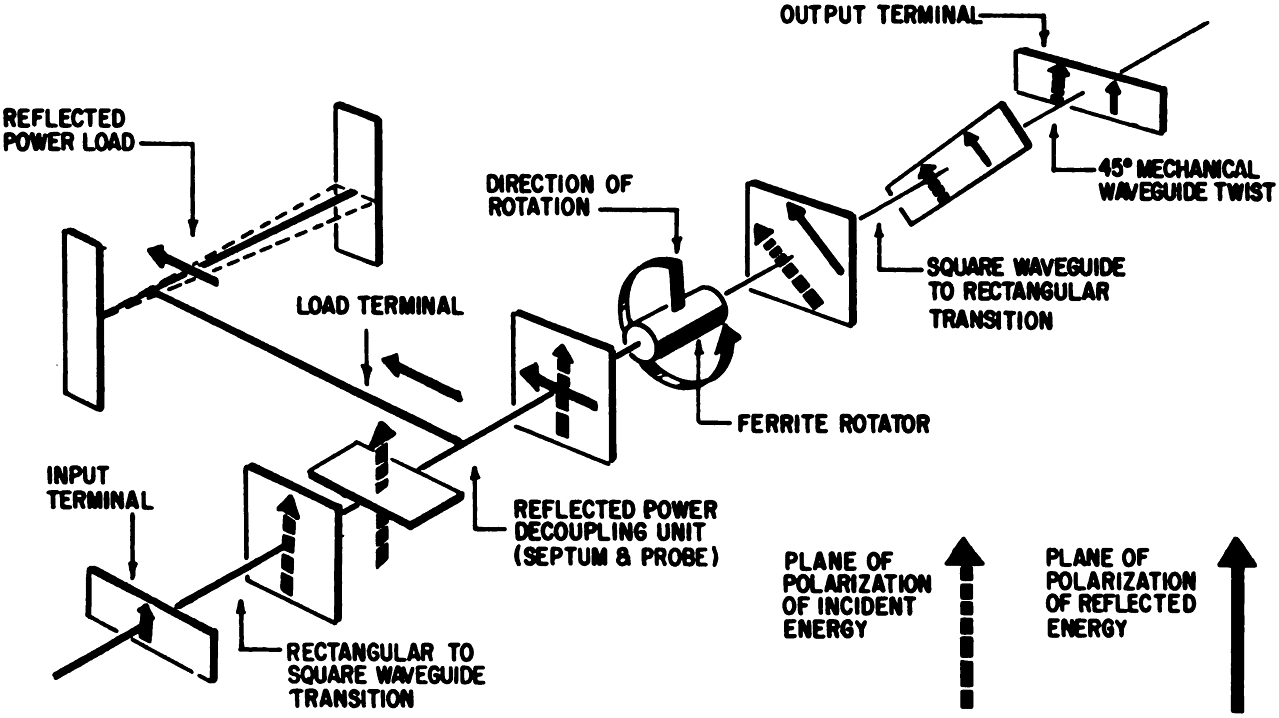

WAVEGUIDE
FERRITE
POLARIZATION OF LEAVING WAVE
D-C MAGNETIC FIELD
POLARIZATION OF ENTERING WAVE
POLARIZATION OF ENTERING WAVE
D-C MAGNETIC FIELD
POLARIZATION OF LEAVING WAVE

AQ.68
Figure 6-29.—Faraday rotation.


FERROMAGNETIC MATERIAL AND PERMANENT MAGNET
TRANSFORMATION FROM CYLINDRICAL TO RECTANGULAR WAVEGUIDE
OUTPUT ENERGY
INPUT ENERGY
DIRECTION OF ROTATION
(A)
FERROMAGNETIC MATERIAL AND PERMANENT MAGNET
TRANSFORMATION FROM RECTANGULAR TO CYLINDRICAL WAVEGUIDE
INPUT ENERGY
OUTPUT
DIRECTION OF ROTATION
(B)

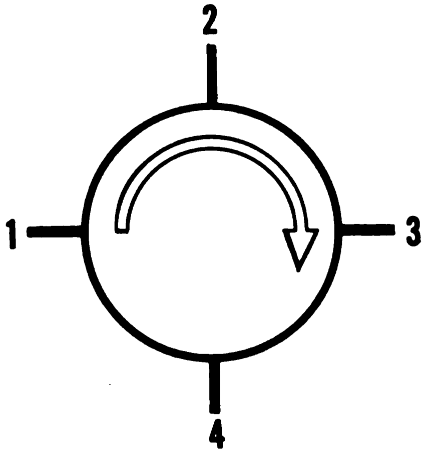
AQ.69

Figure 6-30.—Faraday isolator. (A) Wave traveling in the forward direction; (B) wave traveling in reverse direction.


OUTPUT TERMINAL
REFLECTED POWER LOAD
45° MECHANICAL WAVEGUIDE TWIST
DIRECTION OF ROTATION
SQUARE WAVEGUIDE TO RECTANGULAR TRANSITION
LOAD TERMINAL
FERRITE ROTATOR
INPUT TERMINAL
REFLECTED POWER DECOUPLING UNIT (SEPTUM & PROBE)
PLANE OF POLARIZATION OF INCIDENT ENERGY
PLANE OF POLARIZATION OF REFLECTED ENERGY
RECTANGULAR TO SQUARE WAVEGUIDE TRANSITION

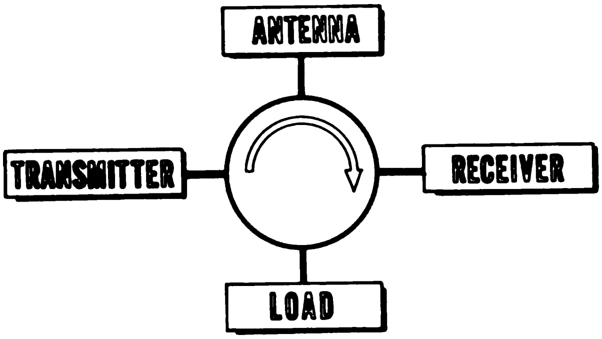
AQ.70

Figure 6-31.—Faraday isolator with a separate load for absorbing reflected power.

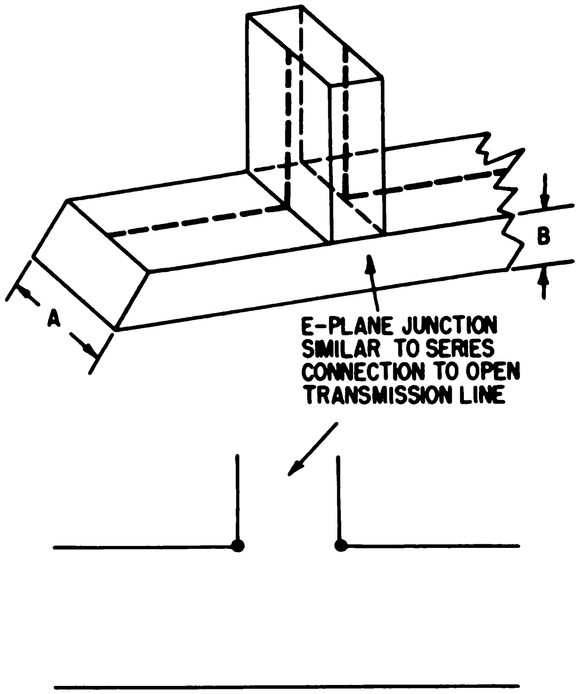


AQ.71
Figure 6-32.--Four-port circulator.

waveguide path to which connections are made at four critically spaced E-plane waveguide junctions. An E-plane (series) junction is one where branch arms join the waveguide at right angles across a wide side (A dimension) as illustrated in figure 6-34.



AQ.72
Figure 6-33.--Four-port circulator used as a radar duplexer.



AQ.59
Figure 6-34.--E-plane junction.

This type of junction is similar to a series connection to an open two-wire transmission line. Figure 6-35 shows the electric fields in successive wavefront positions for an analysis of an E-plane junction.

Signals arriving at the junction from the branch waveguide (fig. 6-35 (A)) divide and are propagated down both of the inline arms, the two signals leaving the junction 180° out of phase. In-phase signals arriving at the junction from the inline arms (fig. 6-35 (B)) combine in the branch waveguide 180° out of phase and, if equal, cancel each other. Signals 180° out of phase arriving at the junction from the inline arms (fig. 6-35 (C)) combine in the branch waveguide in phase and add.

The total length of the ring duplexer illustrated in figure 6-36 is one and one-half wavelengths; the branches are spaced one-fourth

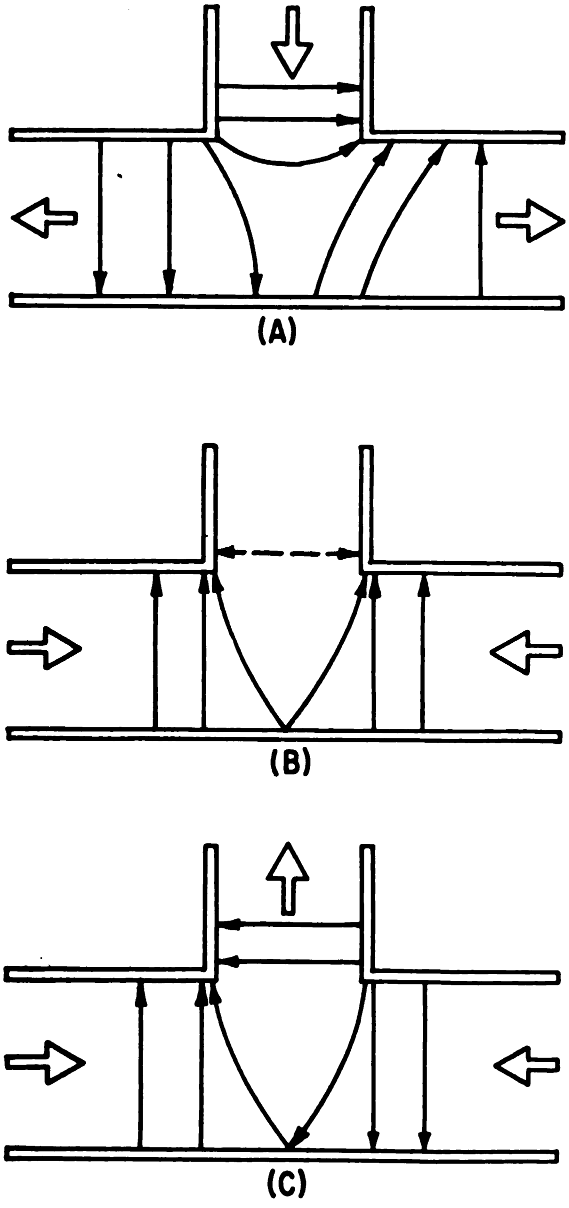
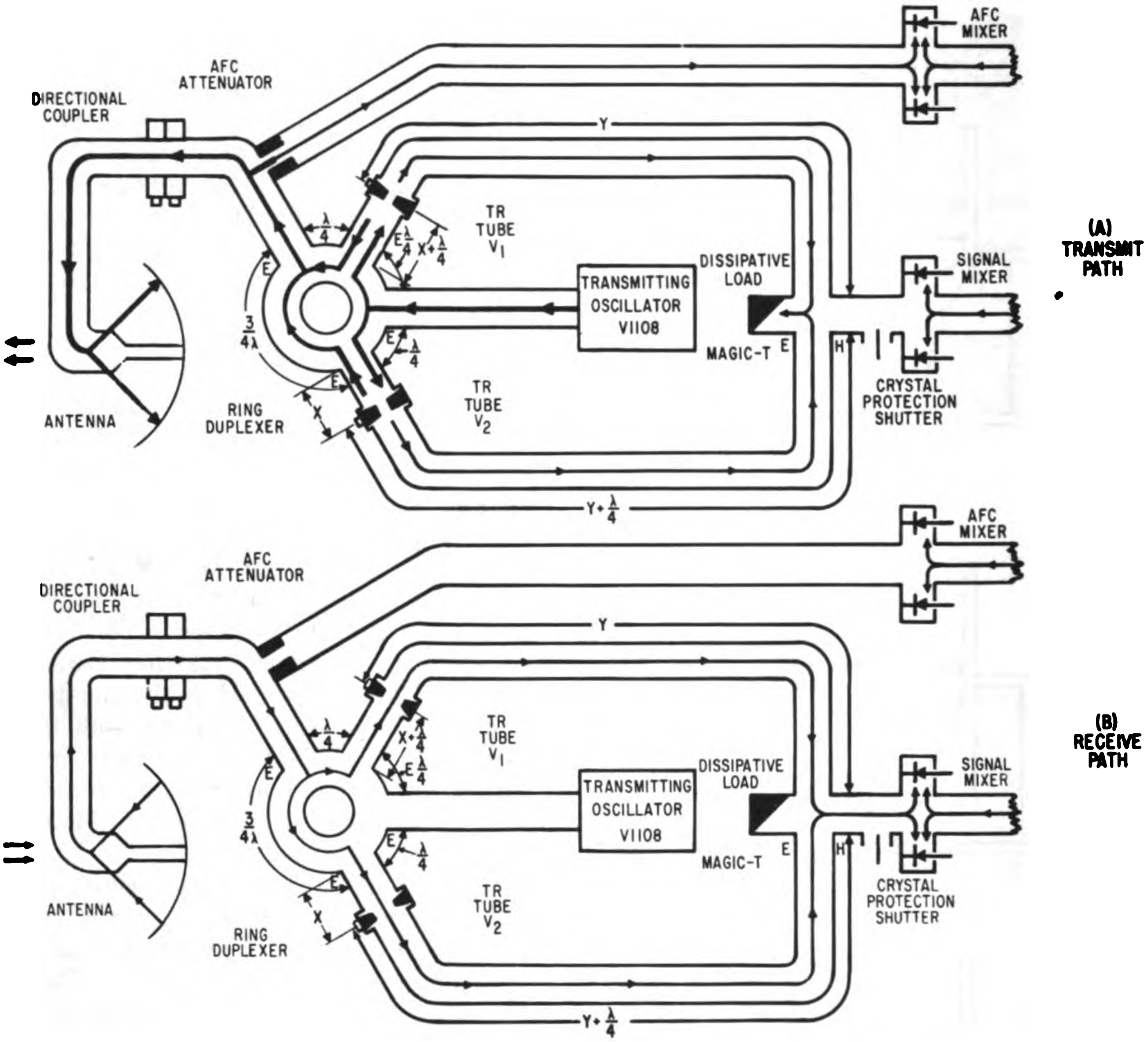


Figure 6-35.–Electrical properties of waveguide junctions.

wavelength apart. The RF signal from the transmitting oscillator enters the hybrid ring duplexer and divides as illustrated in figure 6-36 (A). The two out of phase signals start in oposite directions around the ring. The signals enter the two arms of the duplexer leading the TR tubes V1 and V2. The TR tubes ionize, short circuiting the paths as in the duplexer assemblies previously discussed. Most of the energy in the signals is reflected back toward the ring duplexer. The weak signals leaking past the TR tubes, illustrated by the light lines in figure 6-36 (A), travel equal distances and arrive at the magic T-junction 180° out of phase. These signals thus enter the E-plane junction and are absorbed by the dissipative load. Transmitter energy does not enter the H-plane junction leading toward the signal mixer since out of phase signals cancel at this type of junction. The reflected energy from the TR tubes proceeds around the duplexer to the arm which is connected to the antenna. TR tube V1 is one-quarter wavelength further from the ring duplexer than TR tube V2; the energy reflected from this tube thus travels one-half wavelength farther in the TR-tube arm. This signal travels one-half wavelength in the ring duplexer while the signal reflected from V2 travels one wavelength in the duplexer.

have traveled equal distances when they reach the antenna junction and, since they left the magnetron arm out of phase, they arrive at the antenna junction out of phase. The antenna junction is also an E-plane junction; the two signals thus add and pass out through the transmitter arm. A greatly attenuated sample of the transmitted signal is taken from the antenna arm of the ring duplexer and conducted by waveguide to the AFC (automatic frequency control) mixer of the receiver section of the system.

The receive cycle of operation of a ring duplexer is illustrated in figure 6-36 (B). The received signals from the antenna leave the antenna arm of the hybrid ring 180° out of phase. The distance traveled by the received signal reaching the magic-T junction through the arm of de-ionized TR tube V2 is one-half wavelength greater than that through the arm of V1. Therefore, received signals combining at the magic-T junction are in phase and enter the H-plane junction leading to the signal mixer.



AQ.61

Figure 6-36.—Ring duplexer.

When the power is off or when the system is in standby condition, a protective shutter is used to slide in the waveguide by relay action to protect the crystal mixers from radiation of nearby radar sets. The directional coupler illustrated provides the same purposes as discussed on other duplexer systems.

Another advantage of the ring type duplexer is that no ATR device is required as with the previously discussed duplexers.

This advantage can be explained through the examination of the basic properties of hybrid junctions. If each of the side arms of the junction are terminated in the characteristic resistance of the arm, then the input impedance at the junction will be equal to the terminating resistance. This will allow for matching pairs of entries in such a manner that no power will be exchanged between entries of pairs. The ring duplexer is balanced in pairs such that the arm from the antenna and the arm from the transmitter are matched, and the two arms containing the TR tubes are also matched. When the input to the ring is from the antenna arm, as it is during receive time, the two voltage waveforms at the transmitter arm combine 180° out of phase. Thus, the output voltage is zero so no power is delivered at the entry to the transmitter, and the power is divided equally between the loads at the arms containing the TR tubes.

CHAPTER 7

SPECIAL COMPONENTS, CIRCUITS, AND SYSTEMS

This chapter is devoted to a discussion of various types of special components, circuits, and systems which the Aviation Fire Control Technician may be required to maintain. The technician should find a knowledge of their construction and operating principles helpful in the performance of aviation fire control maintenance.

TRAVELING WAVE TUBES

The evolution of radar has partially been the result of a continuing need to stay ahead of any new countermeasure tactics which might compromise the radar's effectiveness.

The trend in search radars has been toward much higher power and toward electronic countermeasure (ECCM) techniques that will increase subjamming visibility. A good antijamming radar must be able to shift frequency quickly, and if possible over a wide bandwidth, to avoid the jammer's frequency. The trend in electronic warfare (EW) has also been toward wide bandwidth capability, where the jammer amplifies wide bandwidth noise or may deceptively retransmit the radar pulse to offset the radar's frequency shift tactics.

An amplifying device capable of broad operating ranges, with sufficient output power and efficiency, is necessary since wide frequency bandwidths are essential to the employment of such tactics. The Traveling Wave Tube (TWT) appeared to offer promise in these areas. The Navy, as well as other military service, has been responsible for many of the primary advances in the TWT development principally through such organizations as the Naval Research Laboratory, the Office of Naval Research, and sponsorship of development contracts with a number of industrial firms.

The TWT is an electronic amplifying device which accepts a weak RF input signal and amplifies it many thousand times. Although it performs the same function as its principal predecessors—the triode, magnetron, and klystron, it has, however, one characteristic not shared by these devices: extremely wide bandwidth. The TWT exhibits relatively uniform characteristics within a 2:1 frequency range; i.e., within one octave. However, it can provide useful gain well outside this range. For example, TWT's are available which will amplify all frequencies from 7,000 to 14,000 MHz; others will handle frequencies from 4,000 to 8,000 MHz, etc., without having to be tuned within their bandwidths. Traveling wave tubes are not normally operated below 500 MHz nor above 10,000 MHz.

Figure 7—1 is a simplified sketch of a helix type TWT structure. At the left of the diagram is

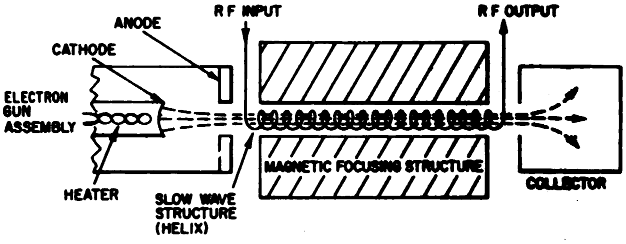


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Figure 7-1.—Simplified helix type TWT structure.

the electron gun assembly. The cathode, when heated, emits a continuous stream of electrons. These electrons are drawn through the anode; are focused into a tight, narrow beam; and are forced to travel the length of the tube, eventually to dissipate in the collector in the form of heat. At the same time the electron beam is moving through the tube, the desired RF signal is fed into a slow-wave structure consisting of, in this case, a tightly wound wire called a helix.

SLOW-WAVE STRUCTURE

The applied RF signal propagates around the turns of the helix at approximately the velocity of light; however, the axial RF electric field (because of the signal) advances toward the collector at a velocity considerably less than the velocity of light. The rate of advance of the RF wave is approximately equal to the velocity of light multiplied by the ratio of helix pitch to helix circumference. The helix is designed to slow down the wave propagation so that it can by synchronized with an electron stream which has a velocity that corresponds to an accelerating voltage of approximately 1,500 volts.

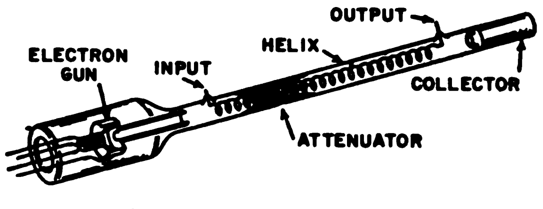
The helix type slow-wave structure is particularly suitable for achieving wideband operation. The reason for this is that the velocity of the axial field produced by the helix is almost completely independent of frequency over a wide frequency range. A typical helix type traveling wave amplifier has a response which is constant to within ±3 db from 2,000 to 4,000 MHz.

Many other types of slow-wave structures may be used in a traveling wave tube (e.g. a folded line, a periodically loaded waveguide, etc.); however, all except the helix are dispersive structures; i.e., they have a wave velocity that varies with frequency and so have less bandwidth than the helix. (Keep in mind that a traveling wave tube will amplify all frequencies for which the velocity of the wave is substantially the same as the velocity of the electron beam.) The helix type traveling wave tube is a relatively low-power device. High-power traveling wave tubes nearly always have less bandwidth.

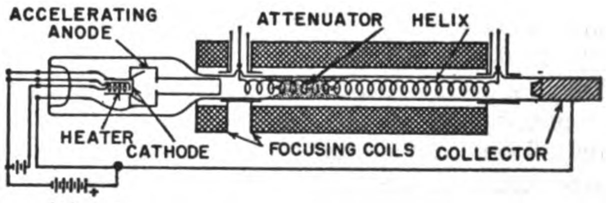
Since the basic theory of all traveling wave amplifiers is essentially the same (regardless of the type of slow-wave structure), this discussion will be confined to the helix type.

The phase velocity of the RF wave, or the speed at which the wave is moving forward, is made synchronous with the velocity of the electron beam. The result is that an interaction is created between the electron beam and the RF signal. It is such that the electrons in the beam are slowed by the RF field and move down through the helix in bunches. As the electrons are slowed, they give energy to the RF field, resulting in great amplification of the RF signal by the time it reaches the output.

As shown in figure 7–2, a magnetic focusing field is provided to prevent the beam from spreading and to guide it through the center of the helix. A helix attenuator, commonly in the form of a conducting coating of aquadag painted on the glass wall of the tube, is required to prevent the amplifier from going into oscillation as the result of backward waves and/or reflections as the result of slight impedance mismatches at the terminals. The RF signal to be amplified is applied at the gun end of the helix and travels its length; output power is removed at the collector end of the helix.



(A) TRAVELING WAVE TUBE



(B) TUBE MOUNTED IN MAGNETIC FOCUSING DEVICE

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Figure 7-2.—Diagram of a typical traveling wave tube.

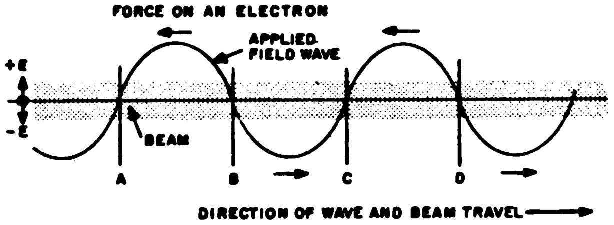

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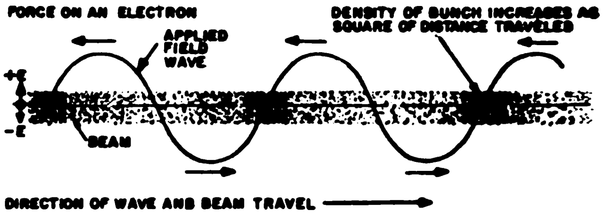
Figure 7-3.—Beginning of the continuous interaction process.


FORCE ON AN ELECTRON
APPLIED FIELD WAVE
DENSITY OF BUNCH INCREASES AS SQUARE OF DISTANCE TRAVELED
+E
-E
BEAM
DIRECTION OF WAVE AND BEAM TRAVEL

AQ.116

Figure 7-4.—Electron bunch density grows with square of distance covered.

INTERACTION PROCESS

To understand the continuous interaction process, consider a constant-amplitude traveling wave of RF electric field as shown in figure 7-3. The positive half-cycle of the RF electric field is tending to force the electrons to the left; and during the negative half-cycle, the wave is tending to force electrons to the right. To begin with, a uniform distribution of electrons is traveling to the right at exactly the same velocity as the wave shown in figure 7-3.

Note that electrons between C and D are falling back and accumulating at C; also, electrons between B and C are advancing and accumulating at C. In other words, a bunch is forming at C, and electrons in the half-periods on either side of B are moving away from B with the consequent formation of an antibunch at B. The bunch-formation process tends to be cumulative; that is, the longer the electrons are subjected to the field, the denser the bunch they form. The result of this process is indicated in figure 7–4. If the traveling wave field remains constant, the charge density of the bunches grows as the square of the distance traveled until the charge density approaches a maximum.

It is important to note that if one observes the passage of the traveling wave and electron stream from a stationary position, the wave will appear as an a-c (RF) voltage and the bunches will appear as an alternating (RF) current. The amplitude of the alternating current (essentially charge density) is proportional to the square of the time electrons have been subjected to the field.

As these electron bunches move through the helix, they induce power on the helix and set up other traveling waves. The core of the helix may be considered to be divided into a series of gaps of minute lengths. The voltage across each gap and the current through each are continually changing as the traveling wave and bunches pass by them. The action of the beam may be analyzed on the basis of the action at each gap separately. Then the total effect may be obtained by adding the actions at the separate gaps in proper phase. The induced power may be

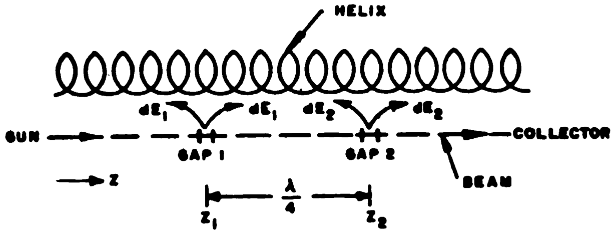


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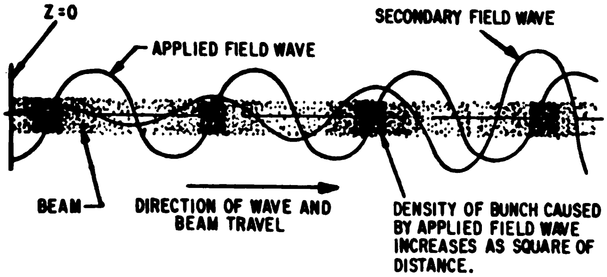
Figure 7-5.—Electron bunches induced opposite traveling field waves on the helix.

resolved into an induced field wave traveling to the right, as indicated in figure 7-5. For example, at gap 1, induced field waves dE_1 are propagated to the left and right from z_1. Similar waves are initiated at all other values of z. The total field at any z is the sum of all induced waves arriving at that z from both directions.

Assuming that the electron velocity is equal to the traveling wave velocity, all field waves traveling to the right will add exactly in phase and cause a secondary field wave to build up 90° behind the original applied field wave, as shown in figure 7-6. Waves traveling to the left, however, do not add in phase; in fact, some of them add 180° out of phase, and so a backward wave does not tend to build up. Note in figure 7–5 that, when a bunch passes gap 1, backward wavelet dE_1 is initiated with a positive crest; then one-quarter wavelength later, the same bunch initiates backward wavelet dE_2. By the time the positive crest of dE_2 returns to gap 1, dE_1 has passed through 180°, is at a negative crest, and the two backward wavelets will tend to cancel. Actually, dE_2 is greater than dE_1, since the bunch density is greater by the time it arrives at gap 2; therefore, a small total wave will result which is traveling to the left. It is traveling, however, at such a high velocity relative to the beam that it will cause no further interaction with the beam. It can be seen later that the helix attenuator prevents this backward wave from returning to the input terminal where it could cause trouble.


Z=0
APPLIED FIELD WAVE
SECONDARY FIELD WAVE
BEAM
DIRECTION OF WAVE AND BEAM TRAVEL
DENSITY OF BUNCH CAUSED BY APPLIED FIELD WAVE INCREASES AS SQUARE OF DISTANCE.

AQ.118

Figure 7-6.—The applied field wave induces an alternating current (bunching) on the beam which, in turn, induces a secondary field wave.

Secondary Field Wave

As mentioned earlier, the charge density of the bunches begins increasing as the square of the distance traveled. This causes a secondary field wave to be induced in phase with the alternating current (bunch), and therefore 90° out of phase with the original applied wave. However, the secondary field wave actually increases at a rate higher than does the current wave in the beam which induced it. The reason for this is that the bunches are actually inducing the infinitesimal waves which, in turn, add in phase to produce the secondary field wave. It can be proved mathematically that the secondary field wave increases as distance cubed.

The secondary field wave will, in turn, cause bunches to start forming 90° behind the original bunches in the same fashion that the applied field wave produced the original bunching. Since the secondary field wave is a growing wave, this new secondary bunching will increase as the fifth power of distance instead of as the square of the distance as caused by a constant-amplitude field. The secondary bunches then induce a new tertiary wave on the helix which grows as the sixth power of distance, etc.

Total Growing-Wave Concept

The final form of the growing wave traveling down the helix may be realized by adding the series of growing waves (secondary, tertiary, etc.).

We may intuitively arrive at a conclusion by reasoning as follows: Near the input, the strongest field is the applied field, and so the field is relatively constant for some distance. The first increasing wave to have substantial amplitude will be the secondary wave, which is increasing as the cube of the distance. For some distance it will be the dominant wave and the total wave will grow as the cube of distance. Next, the tertiary wave becomes dominant, so the total field appears to grow as the sixth power of distance, etc. Thus, the rate of growth is rapidly increasing as distance increases, and as a result, the rate of growth is increasing as fast as the wave amplitude is growing; i.e., the growth is exponential.

It is obvious that this total field wave is traveling slower than the beam and the original wave, since it is composed of induced wave components, each of which lags the previously induced component by 90°. Thus, energy is actually being transferred from the beam to a composite wave traveling slower than the beam, which, according to mathematics, must be true. An important point can be cleared up now; that is, the velocity of the electron beam does not have to be greater than the velocity of the applied traveling wave in order for the mathematical requirements for energy transfer to be satisfied. In fact, their velocities must be exactly synchronized to result in the most efficient operation.

Energy Transfer

With this method of analysis, the question of how the beam transfers energy to the traveling wave is answered as follows: There is no net energy required to bunch the beam. On the average, as many electrons are speeded up as are slowed down, and no energy is transferred from the helix to the beam in producing bunching. There is, however, a perfectly real energy transfer from the bunched beam to the helix in inducing a growing field on the helix.

In terms of the picture of the beam passing through a series of interconnecting gaps, the beam delivers power to each gap in the same fashion that the bunched beam in a klystron delivers power to the catcher gap. Thus, at each stage of bunching, no energy is transferred; but in setting up each field wave (secondary, tertiary, etc.), the beam transmits energy to the helix.

ELECTRICAL CONSTRUCTION

Electron Gun

The electron gun used in a TWT is quite similar to that of a projector lens; its objective is to obtain as much electron current flowing in as small a region as possible without distortion or fuzzy edges. The design of the gun is extremely important, since the gun is the source of electrons for the beam. A wide variety of guns have been developed in an effort to improve the gun optics to provide better beams.

Cathodes have been made of many different types of materials. Two types have generally become standard—the oxide type, which has a nickel base with a barium/strontium coating; and the disperser cathode or the L-type, one version of which has an emitting surface consisting of porous tungsten through which barium atoms are dispensed from a chamber containing barium-strontium-oxide crystals. Two other types which are also used are the pressed cathode and the impregnated type.

Recently a number of tubes have been developed which have control grids. The use of a control grid makes it possible to turn the beam off and on rapidly with a much smaller voltage swing than is required when the cathode is modulated.

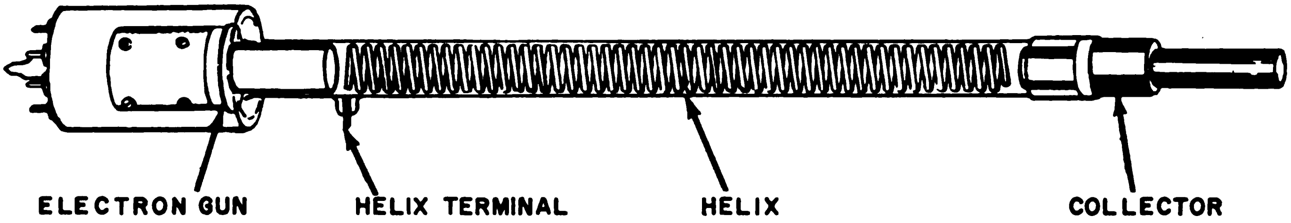


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Figure 7-7.—Principal parts of the helix type traveling wave tube.

Helix Circuit

The helix circuit is considered to be the most efficient TWT circuit. It is capable of producing wider bandwidths than any of the more recently developed versions; however, its design is generally restricted to tubes having peak power outputs of less than 3,000 watts.

Single Helix

Figure 7–7 illustrates the principal component parts of a typical helix tube with its packaging and focusing structures removed. Helix coils are usually made of tungsten or molybdenum and are wound to extremely accurate dimensions. This accuracy is required because the fields associated with the "slow waves" must travel at the same axial speed as the stream of electrons emitted from the cathode. For example, in a 1,500-volt electron beam, the electrons travel at 1/13 the speed of light. Since the RF signal is carried along the wire from which the helix is wound at about the speed of light, the resulting linear ratio of the helix to the beam must approximate 13:1 in this example.

Helix-Derived Circuits

A number of configurations utilizing the basic helix structure have been explored in an attempt to extend its many fine properties to include higher output powers. An early attempt, the contrawound helix, uses two helixes wound in opposite directions. This device extends the useful range of operating voltages to the 20 to 70-kv range and allows the use of larger transverse dimensions at a given frequency range. The ring bar shown in figure 7–8 is a version of the contrawound helix.

Filter Type Circuit

For some time, the TWT was considered usable only as a low-power device. At high powers, the basic helix structure has two major limitations: an inherent tendency to oscillate, and the inability to dissipate the large volume of heat accumulated. Many other slow-wave structures have been investigated in an attempt to find a means of eliminating these undesirable limitations while retaining the TWT's wide bandwidth characteristics. Of the many types of circuits investigated, versions of the filter type have shown the greatest promise.

The simple waveguide is basically a high-pass filter. If a waveguide is periodically loaded, reflections will accumulate from the loading obstacles; and the high-pass filter will become a band-pass filter with characteristics which depend on the nature of the periodic loading.

Fundamental Forward-Wave Circuits

A number of circuits have been developed which employ a perturbation of the basic waveguide mode, where the fundamental wave has its phase and group velocities in the same direction. One of these, the cloverleaf, which is so named because the couplers resemble a four-leaf clover, has achieved up to 2 megawatts of peak power in the 1000 MHz to 6000 MHz range.

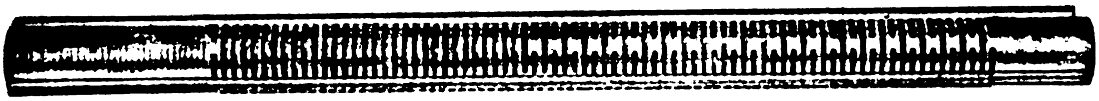

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Figure 7-8.--A contrawound helix.

Spatial Harmonic Circuits

Another broad group of circuits utilizes a coaxial mode perturbed by the waveguide wall. The fundamental wave in these circuits has its phase and group velocities in opposite directions; therefore a harmonic, usually the first, is used. (These are all either backward-wave amplifiers or backward-wave oscillators. Spatial harmonics are also called Hartree harmonics and should not be confused with frequency harmonics. All spatial harmonics are of approximately the same frequency, but are developed at different times as the electron bunch travels through the slow-wave structure; i.e., they are related to the periodicity of the slow-wave structure.) The single slot, double slot, and drift tubes are examples of spatial harmonic circuits. Double slot TWT's have been built which produce 1-megawatt peak output power over a 9-percent bandwidth, with gains also in the 20-to-30 decibel region.

Coupled-Cavity Circuit

One of the most significant developments in recent years has been the utilization of basic waveguide mode resonators, coupled together by means of capacitive or inductive apertures, to provide either a fundamental forward or backward-wave circuit. This device is known as the coupled-cavity circuit. It is also known as a folded-waveguide circuit, since its structure resembles a waveguide folded in accordion fashion. Figure 7–9 illustrates a cross-section view of a high-powered, coupled-cavity tube of the spatial harmonic variety. The gun assembly is shown at the right end of the tube. The input

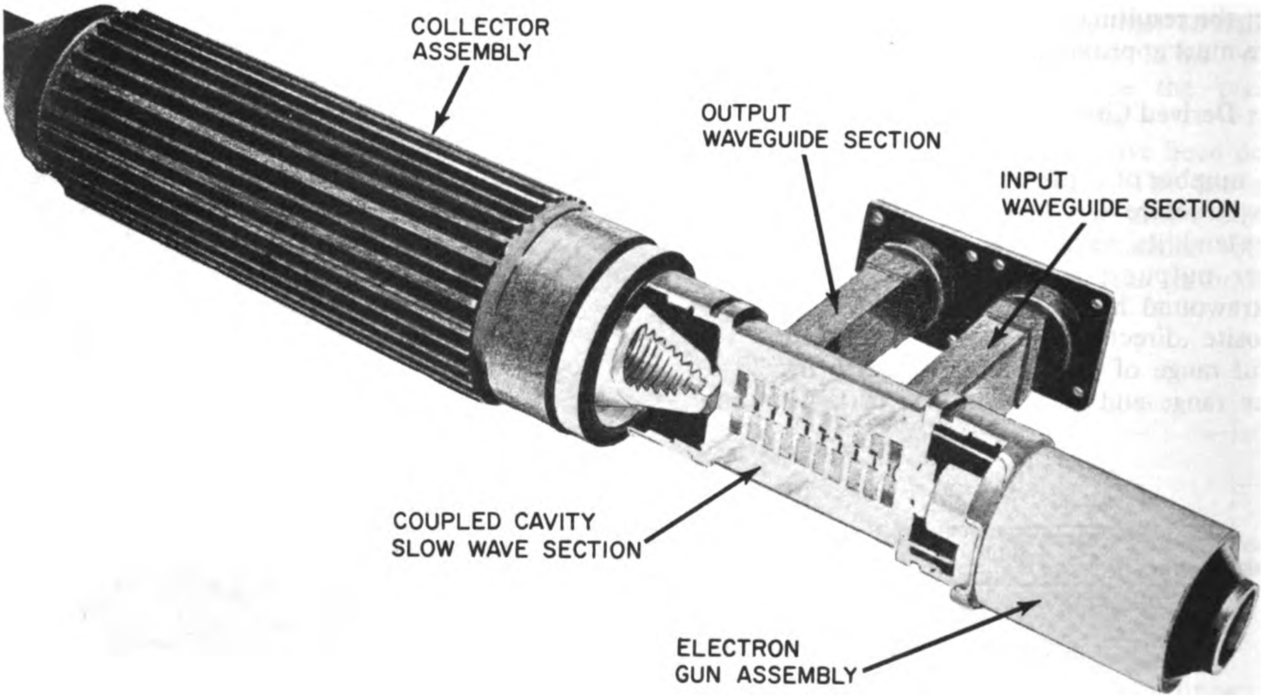

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Figure 7-9.—High-powered coupled-cavity traveling wave tube.

waveguide is at the top right of the slow-wave structure; the output is to the left of the input. The cylindrical structure at the left end of the tube is the collector.

Originally, these structures provided frequency bandwidths of 10 to 15 percent. Recently, however, means have been developed for increasing the bandwidth of these circuits to 40 percent and more; and tubes utilizing this circuit have produced several hundred kilowatts of peak power from 1000 MHz up to 20,000 MHz with up to 50 decibels of gain.

Another version of the coupled-cavity circuit, the interdigital line, has found extensive use in low-and medium-power amplifiers ranging in power output up to 1-kilowatt peak, with gains of about 30 decibels.

Helix Attenuator

The helix attenuator, shown in figure 7–2, was mentioned early in this chapter, but the effect that it has on the traveling waves has been ignored. It is important to note that the attenuator absorbs not only the undesired backward and reflected waves, but it also abosrbs the desired forward applied field wave and growing wave on the helix. In other words, no traveling wave gets past the attenuator in either direction. However, the bunching of the electrons, which the applied wave has accomplished prior to the attenuator, is unaffected by the attenuator. As the bunches of electrons emerge from the attenuating region, they induce the secondary field wave just as described here and shown in figure 7–6. The helix attenuator does not alter the basic theory; but, if we had included the attenuator on the left side of figure 7–6, the applied field wave would not appear on the output side of the attenuator.

Focusing Structures

Since the beam tends to disperse or spread out as the result of the mutual repulsive forces between the electrons, some means is required for holding the electron beam together as it travels through the interaction structure of the tube. A magnetic field of the proper magnitude is used to confine the electron beam to the pencillike cylindrical shape it must maintain. The three principal types of magnetic focusing

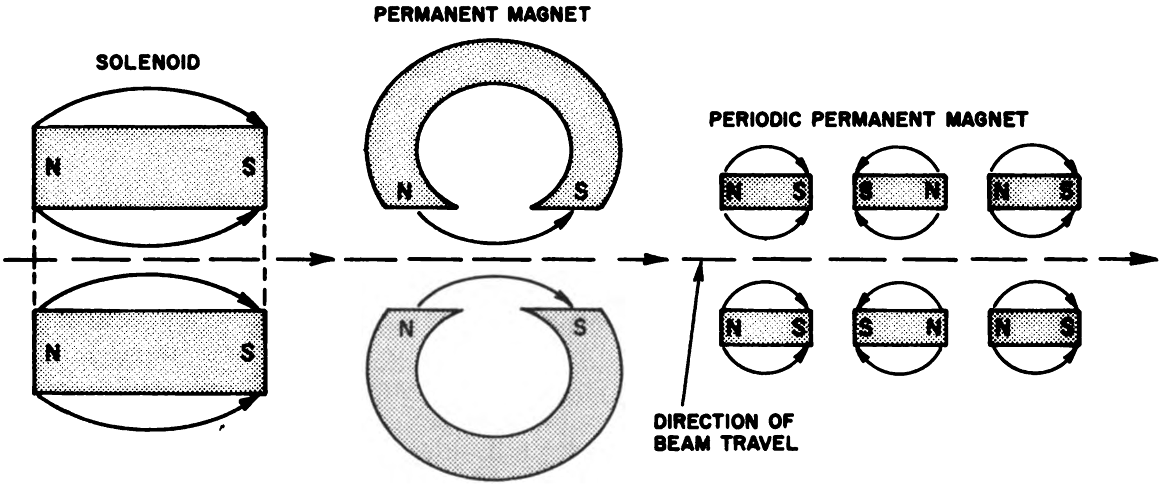

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Figure 7-10.—Three principal types of magnetic focusing.

discussed in this chapter are illustrated in figure 7–10.

SOLENOID FOCUSING.–The solenoid is still regarded as one of the best magnetic focusing structures. Its magnetic lines are parallel to the direction of travel of the electrons; it can be accurately alined with the beam; and it provides excellent beam columniation. It will continue to be used in cases where the last bit of average power is required from a tube and tube size and weight are not critical factors. To date, most of the very high-powered TWT's utilize solenoids. Figure 7–11 shows a very high average powered TWT utilizing a coupled-cavity interaction structure with solenoid focusing.

PERMANENT MAGNET FOCUSING.–In certain tube structures where the interaction structure is short enough, permanent magnet focusing is utilized in lieu of the solenoid. Figure 7–12 illustrates a coupled-cavity type TWT with its permanent magnet focusing structure.

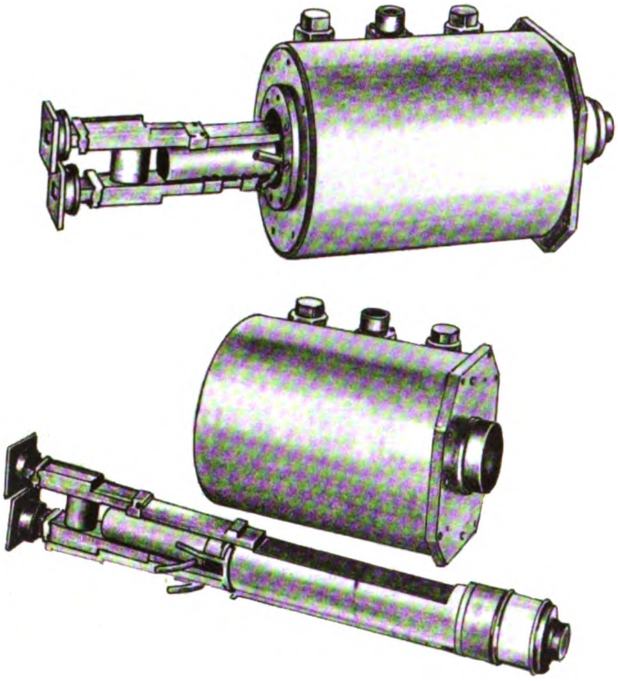

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Figure 7-11.–High-powered TWT using solenoid focusing.

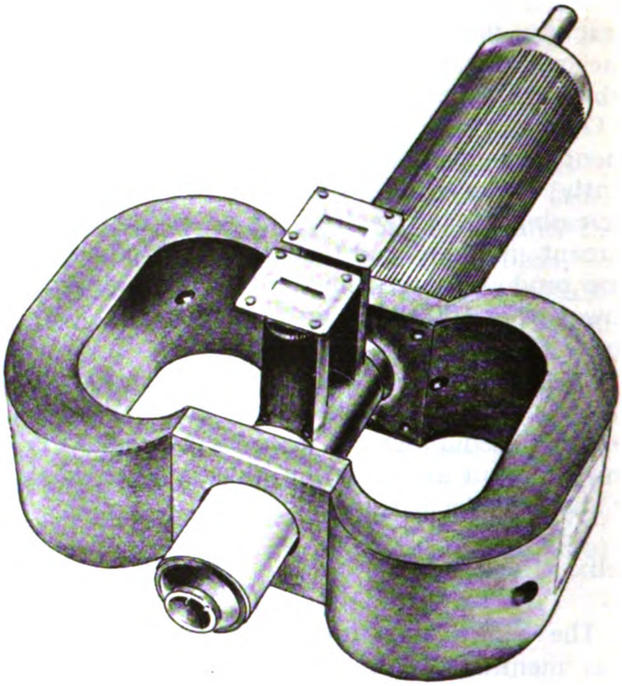

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Figure 7-12.–High-powered TWT using permanent magnet.

PERIODIC PERMANENT MAGNET FOCUSING.–Perhaps the most important development in beam control has been the evolution of periodic permanent magnet (PPM) focusing, particularly its adaption to high-powered TWT's. Previously, its fundamental limitations were thought to restrict its use to low-powered TWT's where the beam power density is typically quite low. This lightweight focusing method fills a great need at the high-power levels where previous TWT's (with focusing solenoids) were too large and heavy for many airborne and space applications.

Figure 7–13 shows a cross-sectional view of a high-powered TWT, complete with focusing

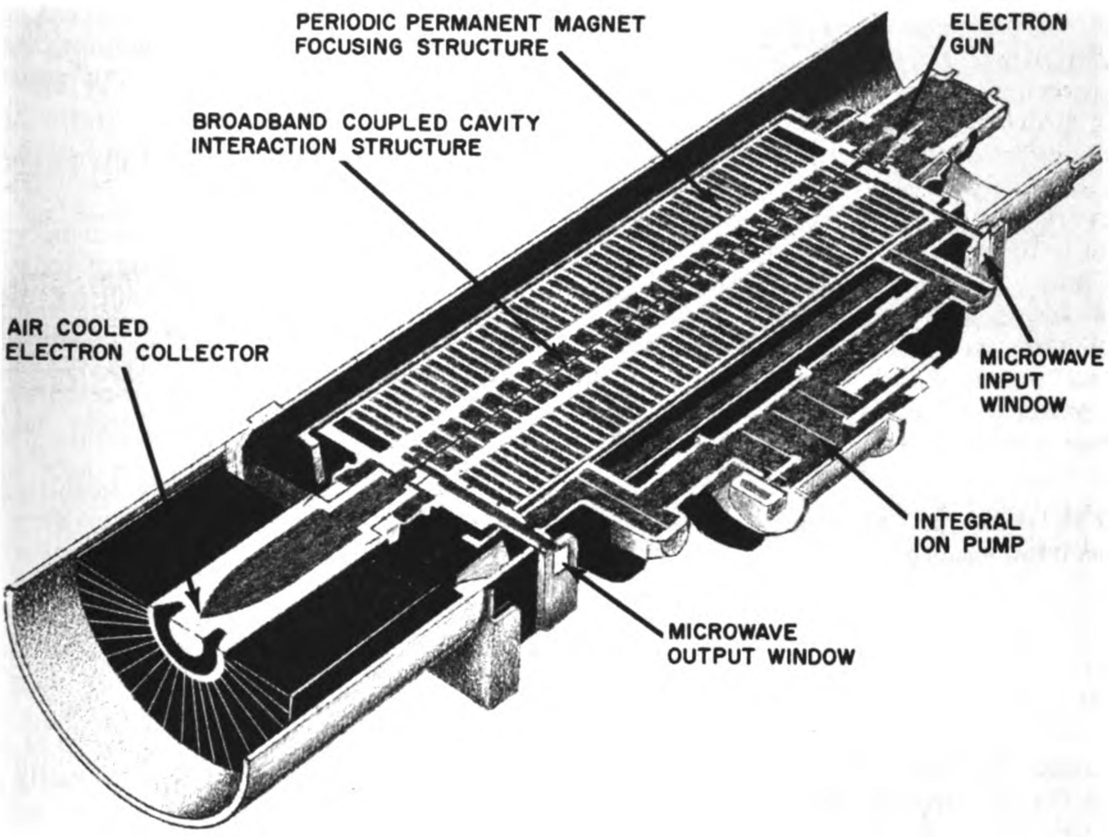
PERIODIC PERMANENT MAGNET FOCUSING STRUCTURE
ELECTRON GUN
BROADBAND COUPLED CAVITY INTERACTION STRUCTURE
AIR COOLED ELECTRON COLLECTOR
MICROWAVE INPUT WINDOW
INTEGRAL ION PUMP
MICROWAVE OUTPUT WINDOW

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Figure 7-13.—High-powered TWT using periodic permanent magnet (PPM) focusing.

structure and external package. The tube is the metal-ceramic, coupled-cavity type and has a total weight of 15 pounds. Its magnetic structure is composed of round disks represented in the cross section by the black vertical areas at the extremities of the interaction structure. These magnets are separated by the lighter colored, iron pole pieces which function as magnet separators and form the interaction structure of the tube.

Figure 7–14 illustrates the use of PPM focusing in a helix type, metal-ceramic TWT designed for space application. The PPM assembly is shown at the top of the figure. This structure is slid onto the helix tube (shown in the middle of the figure), properly alined, and finally packaged as indicated at the bottom of the figure. The tube provides 10 watts of CW power and has a total packaged weight of only 12 ounces.

ELECTROSTATIC FOCUSING.–Electrostatic focusing methods have been experimentally applied to low-and medium-powered TWT's with some success. Electrostatic focusing techniques require no magnetic field and, in principle, could provide even greater compactness and lighter weight than the PPM. However, the techniques currently available have not reached the practical stages where they can successfully compete with PPM focusing.

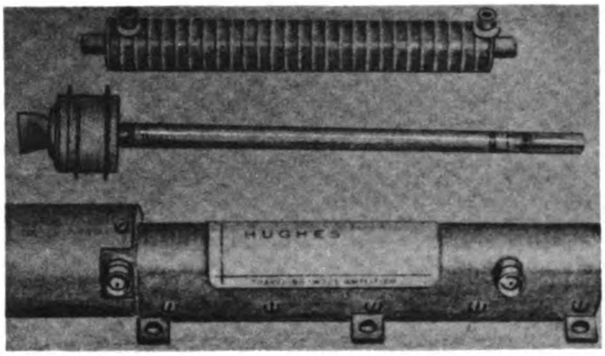

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Figure 7-14.—Helix type TWT using periodic permanent magnet (PPM) focusing.

Collector

The only function of the collector is to dissipate the electrons in the form of heat as they emerge from the slow-wave structure. this is usually accomplished by conduction to a colder outside surface, where the heat is absorbed by circulated air or liquid. The collector size is determined by the method of cooling used and the amount of energy which must be released.

MECHANICAL CONSTRUCTION

A disadvantage of the helix circuit has been the fragile glass vacuum envelope which encloses the tube parts. Actually, however, such glass structures are sufficiently well supported to withstand almost any environment and can tolerate very high shock and loads.

Recently, a means of utilizing metal and ceramic materials in place of glass in helix tube manufacture has been developed. These tubes can withstand higher loads and can be vacuum-fired at higher temperatures—typically 600°-700° C as opposed to 450°C. This assures considerably better cleanup of undesired gases entrapped in the tube, providing improved reliability at higher tube operating temperatures. Figure 7–14 illustrates a very recent version of such a tube. Most other structures discussed in this chapter utilize metal-ceramic construction.

FUTURE DEVELOPMENT AND TRENDS

A capability to amplify over a very wide bandwidth has great significance today in military applications. As a result of the wider bandwidth and higher power capabilities of some of the newer tube types, principally the TWT and its relative, the carcinotron, many existent radar and ECM system designs will rapidly become obsolete.

The efforts of some tube manufacturers to develop higher average powers are being concentrated on CW rather than on pulsed TWT's. Recent requirements for sophisticated Doppler radars, high-power ECM, and space communications have demonstrated an urgent need for high-powered devices, but only over limited bandwidths. It is expected that TWT's will soon be developed which will be capable of replacing these devices, thereby providing vastly superior system capability.

Space applications of radar and electronic countermeasures can be expected to expand along the lines of recent communications developments. Just which radar and ECM techniques will be used in space will depend on the design and mission of the coming space vehicles. Satellites performing reconnaissance and surveillance missions will probably be among the first developed, and it is likely that TWT's will be at the forefront of their systems.

The electronic efficiency of TWT's in other areas is continuously being studied and improved; and efficiency as great as that provided by any other type of structure is being attained. TWT's are beginning to invade both ends of the microwave spectrum. At the lower end, they are replacing triodes in a number of applications; and at the high end, millimeter wave length TWT's are showing excellent progress. At high frequencies this device will offer tremendous communications versatility because it combines broadband frequency range with the security provided by line of sight transmission and reception.

BACKWARD WAVE OSCILLATOR

The "M" type backward wave oscillator (M–BWO) is a wideband, high powered, highly efficient and reliable source of microwave power. It offers high speed, half-octave electronic tuning by variation of a single control voltage. Its most extensive application to date has been in ECM barrage and spot noise jamming.

During the early days of radar, the magnetron, with mechanical tuning, was the workhorse microwave electronic warfare equipment. However, because wide and rapid tuning requirements began to develop for both radar and electronic countermeasures, wideband electronic tuning of high powered microwave oscillators became desirable.

The development of the voltage tunable magnetron and the principle of traveling wave interaction in linear beam tubes stimulated work on crossed field traveling wave devices. This led to the development of the CARCINOTRON, and M-BWO.

The M-BWO has become an excellent microwave transmitter tube because of the following characteristics:

1. The advantage of the M-BWO's voltage tuning over mechanical tuning.
2. The tube's high power and efficiency.
3. Its versatility.
4. Its economy of size and weight.

BASIC PRINCIPLES

The M-BWO is a voltage tunable microwave power generator using the interaction of a ribbon beam traveling near a frequency selective delay line. Electric and magnetic fields are maintained at right angles to each other and to the direction of the beam. The beam velocity is substantially the same as the phase velocity of a wave component traveling along the delay line. By this means, energy is transferred from the static field to the RF field. In the M-BWO, the RF energy travels in a direction opposite to that of the electron beam.

In most practical tubes, the interaction space is ring shaped. Figure 7–15 (A) shows a cross section of a typical tube and shows the path of the electron beam and the RF energy under oscillating conditions. Figure 7–15 (B) illustrates a three-dimensional cross sectional view of an earlier M-BWO.

The M-BWO is a member of the traveling wave tube family described earlier in this chapter, having in common with it the slow wave device, or delay line, and the bunching of electrons in the beam. The M-BWO differs from the TWT in several ways, including the use of the crossed magnetic field. You will probably recall that crossed magnetic fields are also used in the magnetron.

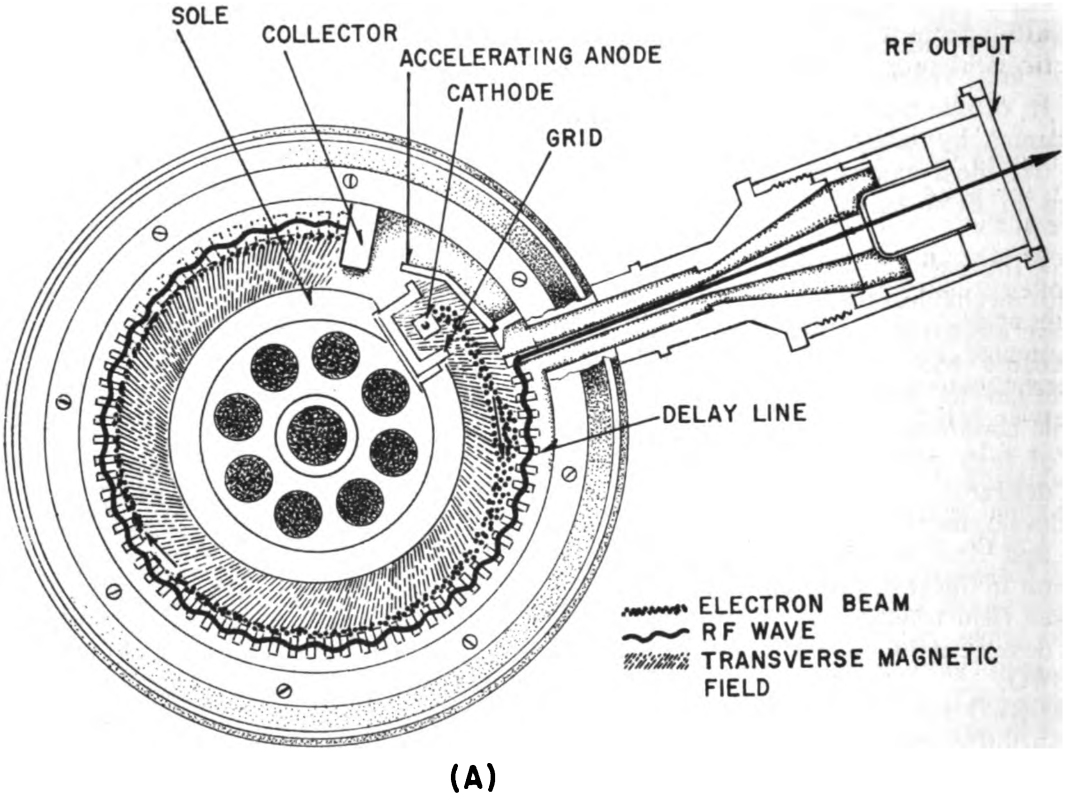
The principle of traveling wave interaction is basic to all crossed field devices. The major objective is to convert electrical energy from static (d-c) form to electromagnetic energy in extremely rapid (microwave frequency) alternating form. The electron is used for this power conversion, since it is able to link the two forms of energy. Reacting initially to the input or static conditions, it takes energy from the input and transports it to another part of the device. Here the energy can be drawn upon to create an output or to amplify microwave signals.

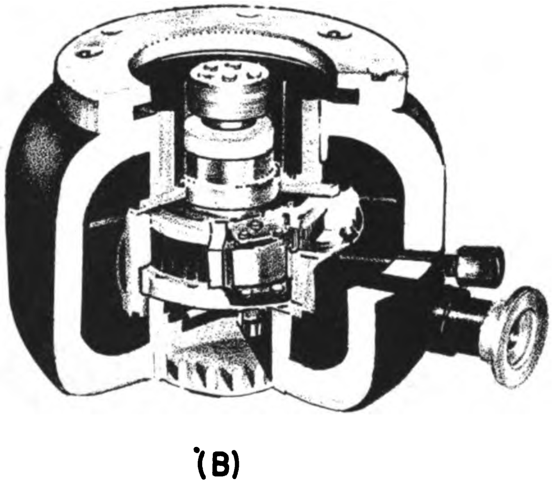
Two elements which require further explanation have been introduced: the path of the electron from its source to its final destination, and the "other part of the device" where the energy of the electron is finally utilized. Each will be considered in turn; then the combining of the two elements to form a working microwave tube will be discussed.

The Electron Path

The path of the electron can best be understood by considering the forces acting upon it. Refer to figure 7–15 (A). The source of all electrons is the cathode. Properly designed and located, the cathode supplies a unidirectional stream of electrons. Immediately after the electrons are emitted, the combined action of magnetic and specially shaped electric fields forms them into a beam.

After the beam is formed, all of the component electrons travel at approximately the same velocity. The negatively charged electrons are injected into an electric field which is perpendicular to their forward motion. (This field arises from voltages applied between opposed elements, the anode and the sole, and in the absence of other forces a given electron would





AT.481
Figure 7-15.—Typical M-type backward wave oscillator.

soon be "collected" by the positive element, the anode.)

However, a second force acting upon the electron arises from its forward motion through a magnetic field oriented crosswise to both the electron path and the previously described electric field; hence, the term "crossed field" tube. By the conventional rule for this situation, the resultant force on the electrons is opposite to the force of the electric field.

Appropriate adjustment of the fields results in a controlled beam path which is circular and terminates at an element called a collector.

To summarize, the electron beam is formed at the electron gun (cathode), follows a circular path between the anode and the sole, and terminates at the collector.

When the forces acting on the beam are expressed in standard electrical terms and equated for the controlled beam condition, the electrical force equals the magnetic force. Therefore, electron or beam velocity is equal to the ratio of electric field strength (E) to magnetic field strength (B). For the practical situation, B is constant and is supplied by a permanent magnet integral with the tube. Thus, beam velocity is directly related to E, the field strength between sole and anode. In more practical terms, E is given by the potential difference between the anode and the sole, divided by the distance between them (which is fixed). Therefore, beam velocity is linearly controlled by variation of either the anode voltage or the sole voltage.

The Delay Line (Anode)

The next step in understanding the basic principles of the crossed field device is to consider the part of the device where the electron beam develops microwave energy.

The sole serves as little more than one of the electrodes for the static electric field, as discussed in the previous section. The anode, however, is a much more complex component than has been suggested. The anode in many crossed field tubes is of such a form that it is called an INTERDIGITALDELAY LINE.

The interdigital delay line is best described as a normal waveguide transmission medium in which opposing walls have been extended towards one another in alternately spaced fingers or digits, as shown in figure 7-16. The velocity wave travel in the resulting interdigital structure is decreased, because of the longer path along its boundaries. In effect, such a structure develops a series of space harmonics whose summation is seen as microwave energy propagated at the delayed or reduced rate.

(One type of magnetron, called the INTERDIGITAL MAGNETRON, uses interdigital transmission line as the interaction space in the generation of RF power. The action of that device is more or less a combination of the conventional magnetron and the backward wave oscillator.)

A particular delay line can be designed for either forward wave or backward wave propagation. The distinction between the two arises from comparison of the direction of the dominant space harmonic with the direction of the energy which sustains it.

The amount of delay is established by adjusting various dimensions within the line. As with the more familiar waveguide, the delay line is a broadband device capable of transmission over a considerable frequency range. Its physical shape is a matter of convenience and, in this case, it is circular.

Production of the space harmonics is the same as in any oscillator, starting with noise and

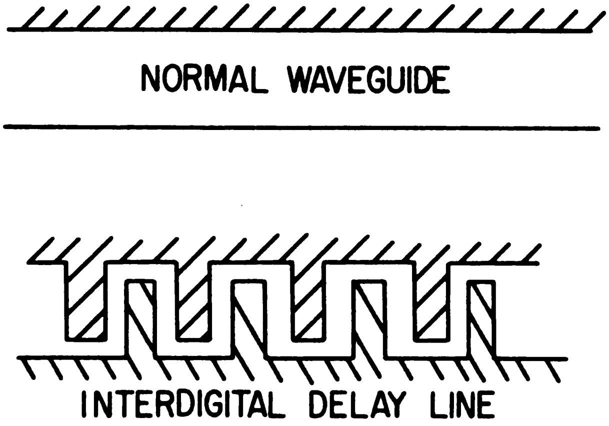


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Figure 7-16.–Interdigital delay line compared with a normal waveguide.

leading to generation of usable frequencies. These frequencies are determined by the fields of the device in a manner similar to the action of a magnetron.

In brief, the electrons serve as a link between the externally applied input energy and the microwave output energy. The electrons determine, by their velocity, the output frequency in an oscillator (and the optimum frequency for an amplifier). At the same time, they determine by their quantity (beam current magnitude) the power output level.

In contrast with magnetrons, the use of a beam in crossed field tubes eliminates cathode back bombardment, thus increasing emission life. In comparison with linear beam devices such as a traveling wave tube, where beam velocity (and therefore tube frequency) are functions of the square root of the tuning voltage, BWO's provide a very nearly linear relationship between tuning voltage and tube frequency.

Interaction

As the electron beam travels in a circular path between the sole and the anode (delay line), electrons of the beam pass near the fringe fields of the noise generated space harmonic waves on the delay line. For electrons of a given velocity, as determined by the externally applied delay line voltage, space harmonics of synchronous phase velocity result. Whether these are forward or backward waves is determined by the design of the delay line. In either case, since phase velocity of space harmonic waves is, in general, a function of frequency, it is the velocity of the electrons that determines the operating frequency.

The total field in this case is a combination of the externally applied fields and the internally developed space harmonic field. By following the laws governing electron motion in crossed electric and magnetic fields, electrons drift in a direction perpendicular to the space harmonic fields. This drift is such that they congregate in bunches, one bunch per space harmonic wavelength.

In the bunches, electrons work their way across from the original beam position to the slow wave structure (delay line), staying locked in synchronism as they do so. Their direction of motion is such that they give up to the RF field the energy acquired from the d-c source, thus causing the space harmonic wave to grow.

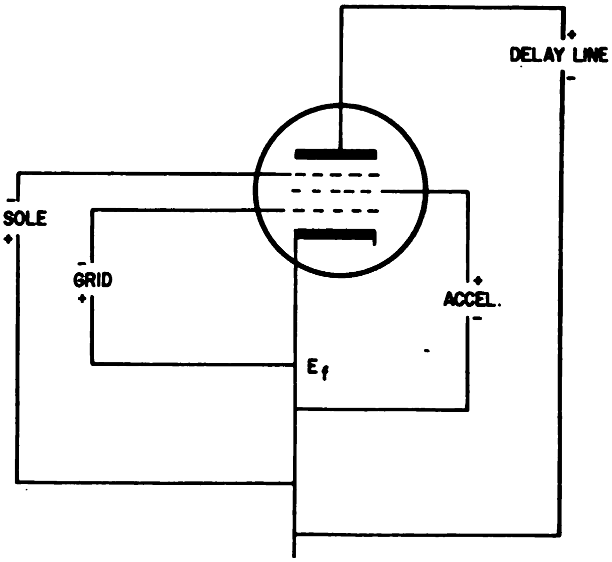
PHYSICAL AND ELECTRICAL CHARACTERISTICS

The basic elements of the M-BWO together with the usual polarities of applied d-c voltages, are indicated in figure 7-17. The arrangement of the basic elements can be separated into three regions as follows:

1. The gun region, including the cathode, grid, and accelerator.
2. The interaction space, including the delay line and the sole.
3. The collector element and the sole.

In practical tubes, the collector and the delay line are integral parts of the tube body and are maintained at ground potential. An exception is that the "beam miser" (to be discussed later in this chapter) places the collector at cathode potential.

The electron gun comprises a heater, cathode, control grid, and accelerator anode. The control grid is operated at zero potential or slightly



AT.483
Figure 7-17.—Schematic equivalent of an M-BWO.

negative with respect to the cathode. The accelerator electrode is maintained at a positive potential with respect to the cathode. The sole electrode is negative with respect to the cathode, and the delay line (commonly referred to as an anode) is positive with respect to the cathode.

With appropriate values of applied potentials and appropriate value and direction of magnetic field, the electron beam is formed in the gun regions, passes through the interaction region, and is collected at both the delay line and the collector.

In backward wave oscillators there is no RF input, and a portion of the delay line adjacent to the collector is modified to assure absorption of any power reflected from the output.

The principal projections from the main tube body are the RF output connector and the HEADER, through which the electrode leads are brought out to external terminals. A doughnut shaped magnet is used, since this form combines high internal magnetic field strength with excellent external magnetic self-shielding properties.

FREQUENCY TUNING AND MODULATION

The oscillator can be tuned through the designed range of frequencies by varying the delay line-to-cathode or sole-to-cathode potential. This can be done statically or dynamically at rates limited chiefly by modulating power and interelectrode capacitances.

The average rate of tuning for a given tube design will be nearly linear throughout the range and very similar from tube to tube. The sensitivity differs in present tubes of different frequency ranges from approximately 0.13 MHz per volt at X-band frequencies to approximately 1.0 MHz per volt at K-band frequencies. The sole potential can be varied for frequency modulation with the advantage of requiring less modulating power. Since frequency is determined by the anode-to-sole potential, both sole and anode (delay line) tuning sensitivities are essentially the same. Sole modulation is limited to one-half of the complete tuning range of the tube, due to tube electronic characteristics.

Amplitude Modulation

Amplitude modulation is accomplished by varying the accelerator potential, since this electrode controls delay line current. Accompanying the amplitude modulation is an inherent frequency modulation resulting from frequency pushing. (Frequency pushing is defined as an RF frequency variation due to a variation in anode current.) Pushing is not linear over either the frequency range or the current range. Amplitude modulation linearity is good, but may be limited at low modulation frequencies by cathode fatigue during high current peaks. The grid electrode should not be utilized for amplitude modulation purposes. A d-c potential on the grid may be required for optimum tube efficiency.

Pulse Modulation

Although these tubes have been designed primarily for CW operation, it is possible to pulse the accelerator electrode and obtain peak power output considerably in excess of the CW power. Some delay line current is present even at zero accelerator potential. In some cases, therefore, it may be desirable to bias the accelerator negatively to obtain complete cutoff, and pulse positively from the level of cutoff bias.

INSULATION AND COOLING

Normal heat dissipation, principally at the delay line and collector, usually requires that external liquid cooling be provided to this region. A coolant channel, an integral part of the delay line, serves this purpose, with coolant being provided through external connections. The coolant generally used is Dow Corning 200 silicone oil, a thermally stable oil with a high resistance to change in temperature. For high altitude operation, the input bushing can be pressurized or immersed in an insulating liquid. In some applications, the tube is operated with the cathode at ground potential. When this method is used, primary to secondary high voltage insulation of the various supply transformers is unnecessary; but high voltage isolation of the RF output connector is necessary and additional safety precautions are required.

SPECIAL CONSIDERATIONS

Most microwave tubes have characteristics which limit their use or which require special consideration in their use. The following is a list of these factors, which the designer must bear in mind as he uses the tube in a system and which are also of interest to the operator:

1. Voltage tuning sensitivity at X-band frequencies is approximately 1 MHz per volt. Thus, for a CW signal, the power supply must be well regulated, with a low ripple factor. Although the average tuning sensitivity is nearly linear over the frequency range, there are variations in sensitivity for small frequency changes.
2. The sole current changes in magnitude with frequency tuning, and it can be in either direction.
3. Frequency pushing results from variations of other tube parameters. This may or may not be significant.
4. Interelectrode leakage current of a small value exists in tubes of present design.
5. A small amount of frequency pulling is a characteristic of the M-BWO. These tubes are, therefore, somewhat susceptible to load VSWR (voltage standing wave ratio) variations. Generally, load isolators are not required when load VSWR's are equal to or less than 1.5 to 1.
6. After full beam current has been established, stabilized frequency will be reached in 2 minutes or less.
7. Interelectrode capacitances must be considered as modulating frequencies are increased.
8. Power output varies over the tuning range primarily due to the necessary change in input power when tuning. Therefore, a 3-db power variation may be encountered over the tuning range.

THE BEAM MISER

The BEAM MISER is a unique type of depressed collector utilized in the beam type, crossed field traveling wave tubes. It permits significant increase in efficiency and power with no additional external connections or other changes in tube or circuit. The depressed collector is one which operates at a lower voltage than the anode or delay line, rather than at the same voltage.

The beam miser consists of a collector internally connected to the cathode and consequently at cathode potential. Thus the anode current is reduced for a given beam current, or the beam current is increased for a given anode current. In an analogous sense, the beam miser has some of the advantages of a reentrant electron beam in crossed field tubes. A considerable part of the spent beam which is unused can be returned to the cathode instead of being wasted by normal collection at anode potential.

The use of a beam miser in standard M-BWO's has permitted increases of power of the order of 30 percent for normal operating anode currents. It has also permitted suitable operation of one tube at several power levels; that is, multiple operating current capability. A tube with a beam miser requires no external mechanical changes or additional electrical input connectors and is, therefore, directly replaceable in the same socket as a standard tube not having a beam miser.

PARAMETRIC AMPLIFIERS

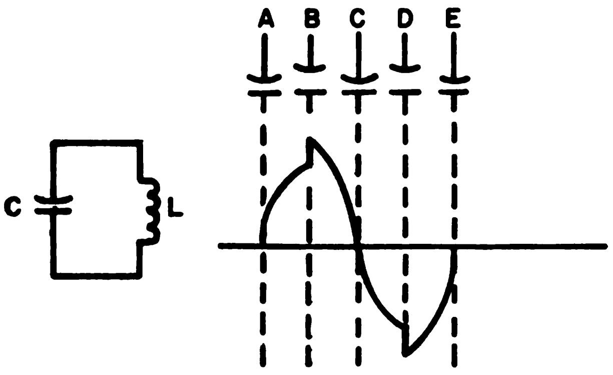
The parametric amplifier, or reactance amplifier, is a device capable of low-noise amplification. Seldom has a device gone so rapidly from the laboratory into operation. The low-noise amplification afforded by these devices offers phenomenal radar range improvements on existing equipments with minimum cost and maximum economy.

The parametric amplifier increases the power level of a signal by means of the variation of an energy-storage parameter. An everyday example is that of a child on a swing. The oscillation is maintained by "pumping"; that is, the child lowers his center of gravity on the downswing and raises it on the upswing. For maximum oscillation, the pumping takes place at twice the frequency of oscillation.

PRINCIPLES OF OPERATION

The principle of operation of one form of parametric amplifier can be illustrated by an LC circuit oscillating at its resonant frequency. (See fig. 7–18).

Assume that the plates of the capacitor can be physically separated and returned to the original position. If the capacitor plates are pulled apart as shown at point B and the voltage is at maximum across the plates, then work has been expended on the capacitor since a force had to



AT.489

Figure 7-18.–Capacitor plates varied by a pump.

be applied to separate the plates. This work appears as an increase in voltage across the capacitor since

$$E = \frac{q}{C}$$

and the charge q remains constant while capacitance decreases. (Capacitance is inversely proportional to the thickness of the dielectric:

$$C = \frac{kA}{t}.)$$

Energy has been added to the system by the source which separated the capacitor plates. This energy transfer is referred to as pumping, and the energy source is referred to as a pump.

If the plates of the capacitor are returned to their original separation (point C) when the voltage is zero (zero charge on the plates), then no work is done and the voltage is unchanged. As the voltage passes through the maximum negative at point D, the plates are separated and voltage increases again. The frequency of the pumping source is twice the resonant frequency of the tank circuit.

Several devices may be used in parametric amplifiers to vary the capacitance or inductance electronically. One device most frequently used as a variable capacitor for microwave frequencies is the varactor diode (variable-capacitance diode). The capacitance of the varactor diode may be varied by changing the reverse bias on the diode. A discussion of varactor diodes is presented in Basic Electronics, NavPers 10087-C, Vol. 1, chapter 5.

Degenerate Mode

The simplest parametric amplifier is one which requires the pump frequency to be exactly twice the resonant frequency of the tuned circuit or signal frequency. This mode of operation is known as the degenerate mode. (See fig. 7–19 (A).)

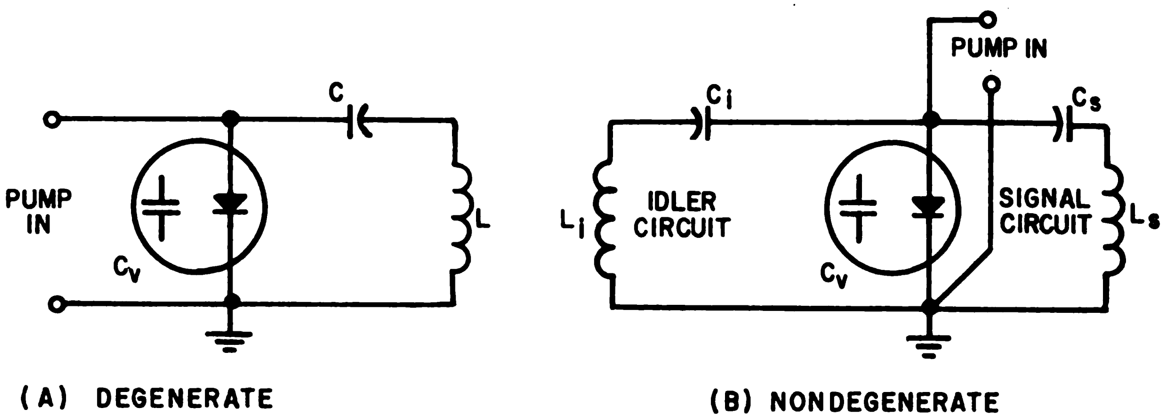
The degenerate parametric amplifier requires a low pump frequency and power to operate, and is the least complex to design. Because it is frequency and phase sensitive, the degenerate amplifier cannot be used in most radar sets.

Nondegenerate Mode

In a practical case, the separation of the signal frequency and the pump frequency cannot be conveniently maintained constant, but will drift in and out of the optimum condition periodically, resulting in modulation of the signal frequency. Thus, the output may contain the pump frequency (f_p), signal frequency (f_s), and the pump frequency plus or minus the signal frequency. The latter is called the idler or image signal (f_i). A parametric amplifier which includes the idler circuit is called a nondegenerate amplifier. (See fig. 7–19 (B).) If the output frequency is higher than the input frequency, the amplifier is referred to as an up-converter. If the output frequency is lower than the input frequency, the amplifier is called a down-converter.

There are three basic configurations of the nondegenerate parametric amplifier which are most often used. (See fig. 7–20.) They are as follows:

1. Two-port sum-frequency (or upper side-band) up-converter.
2. Two-port difference-frequency (or lower side-band) down-converter.
3. One-port difference-frequency parametric amplifier.



AT.490
Figure 7-19.—Basic parametric amplifiers.

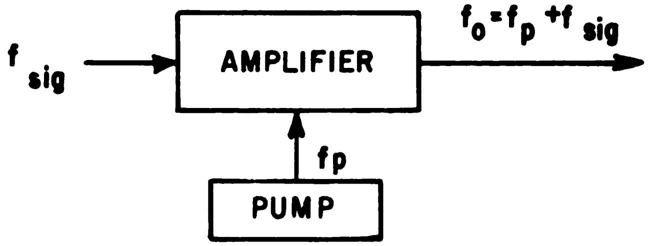
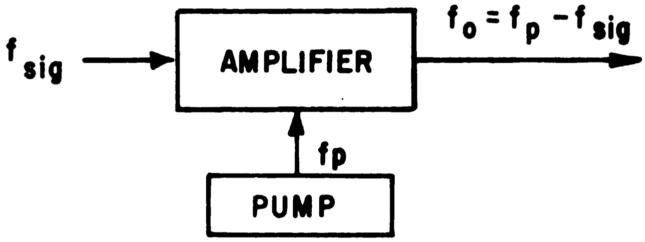
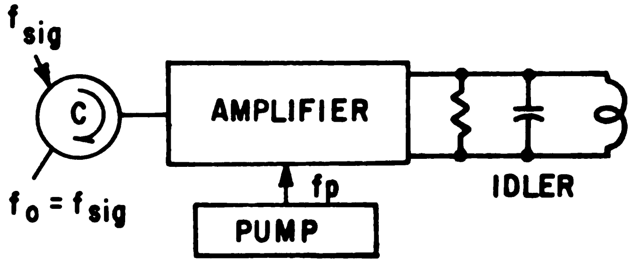
In the two-port sum-frequency arrangement, the overall noise figure is higher than in other modes of operation, and the amplifier has only moderate gain. The pump frequency is less than the signal frequency; and this is important since available pump power decreases with frequency; thus, this amplifier is most useful at the highest frequencies. The name two-port comes from the fact that the output terminals are different from the input terminals. In the two-port difference-frequency mode of operation, the amplifier has a relatively narrow bandwidth, high gain, and a low-noise figure.

In the one-port difference-frequency mode, the parametric amplifier has the lowest noise figure. It is also fail-safe in that the system would continue to operate with near the same noise figure if the pump were to fail. However, a circulator must be used to separate the amplified output from the incoming signal; this also aids in maintaining amplifier stability because it is sensitive to source impedance changes. The operation of the one-port difference-frequency parametric amplifier for the achievement of low-noise amplification (fig. 7–21) is as follows:

The varactor D (variable-capacitance diode) must couple together all the resonant sections at three frequencies–signal, idler, and pump. For amplification to occur, the sum of the idler and signal frequencies must equal the frequency of the pump. The signal frequency must be much lower than the idler frequency to achieve low noise. However, due to the imperfect nature of the varactor, there is an upper limit for the idler frequency at which noise will increase. The capacitance of the varactor will be varied at the pump frequency rate by power from the pump. Some of this power is transferred and added to the signal when the two frequencies are mixed, resulting in power amplification. The output signal is then taken from the circulator, which separates the input and output signals.

TRAVELING WAVE PARAMETRIC AMPLIFIER

The tuned circuits used in the parametric amplifiers discussed in the previous section are usually of the coaxial or cavity type resonators. These amplifiers have a narrow bandwidth (less than 5 percent of the center frequency) because of the high Q resonators. By using a traveling wave structure and sacrificing some gain, parametric amplifiers can be designed to provide

PARAMETRIC-AMPLIFIER MODE	CONFIGURATION
2-PORT SUM-FREQUENCY (or upper sideband) Up-converter.	
2-PORT DIFFERENCE-FREQUENCY (or lower sideband) Down-converter.	
I-PORT DIFFERENCE-FREQUENCY	 f sig C $f_o = f_{sig}$ AMPLIFIER fp PUMP IDLER

AT.491

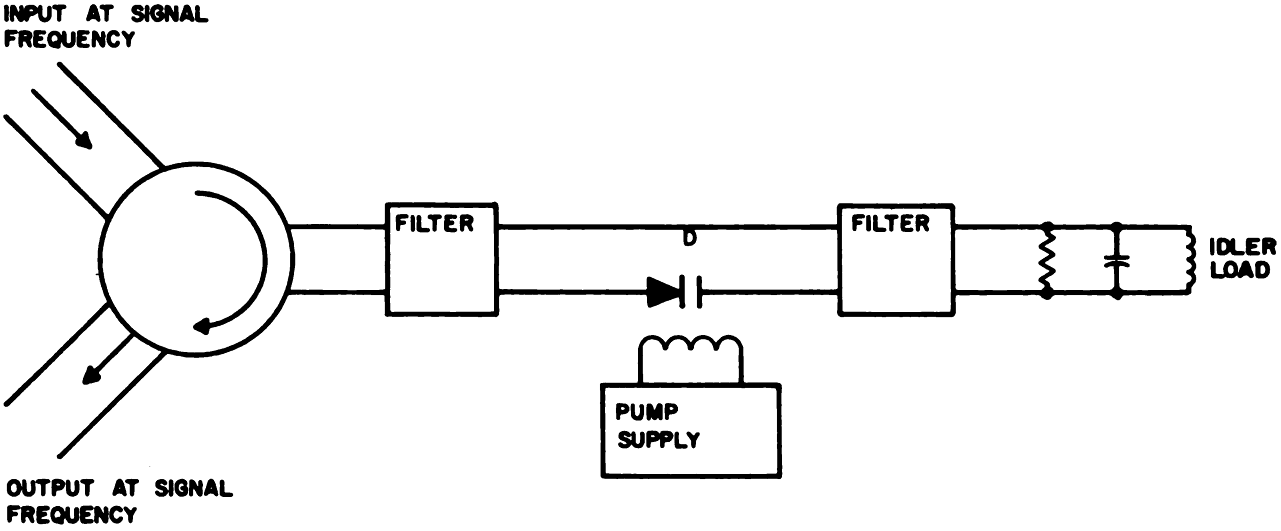
Figure 7-20.—Basic configuration of the parametric amplifier.

bandwidths as high as 60 percent of the center frequency. (See fig. 7–22.)

The traveling wave amplifier consists of a multistage low-pass filter which is composed of a transmission line or lumped inductances and pumped shunt varactor diodes. The filter is terminated at the desired output frequency, and this signal will not be reflected to the input. The signal and pump frequencies are injected at one end of the traveling wave structure and the desired output taken at the opposite end. The signal, pump, and idler frequencies are within the bandpass of the filter and the sum of the pump and signal frequencies are outside the bandpass. As the wave travels down the line, the idler and signal voltages increase as energy is transferred from the pump. Although gain increases as the length of the traveling wave structure is increased, the resistive losses also increase. There is an optimum length of line for maximum gain. The main disadvantage of the traveling wave parametric amplifier is that it has a lower gain than the narrowband amplifier.

DIRECT VIEW STORAGE TUBE

A direct view storage tube (DVST) is similar in many respects to a conventional CRT, but has some differences which make it superior for an

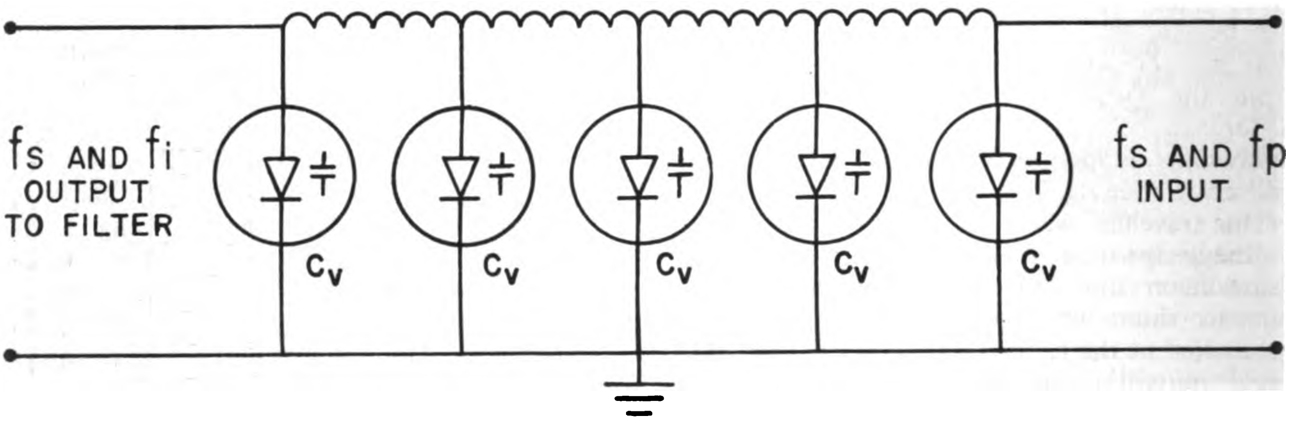


AT.492
Figure 7-21.—One-port difference-frequency parametric amplifier.

airborne radar display. Among its chief advantages are the following:

1. Higher light output when required.
2. Longer persistence of the display highlights.
3. Persistence controllable for adaption to a wide variety of conditions (search/track, etc.).
4. Smaller overall package design is possible.

There are many others that could be mentioned, but the above will suffice for the



AT.493
Figure 7-22.—Traveling wave parametric amplifier.

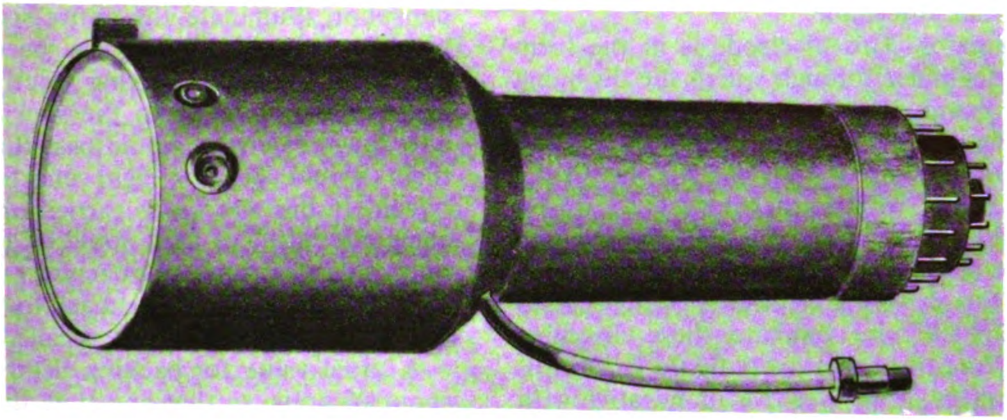


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Figure 7-23.–Direct view storage tube.

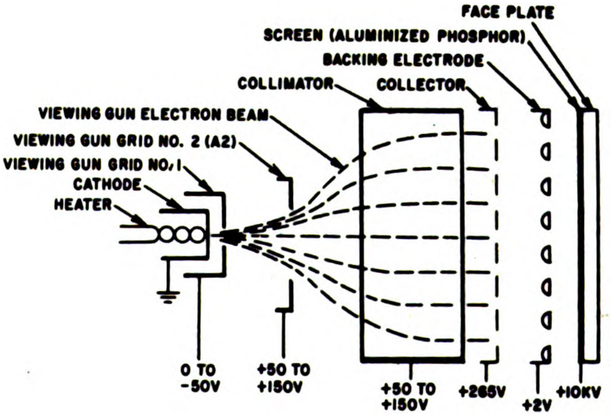
purposes of this discussion. Figure 7–23 shows a DVST. The entire tube is potted within its magnetic shield to provide protection against mechanical shock, vibration, humidity, and leakage between bulb terminals.

The major difference between CRT and DVST display devices is the inclusion in the DVST of a low velocity electron gun known as the viewing or flood gun. It is through this viewing gun that the advantages of the DVST can be realized. It is the viewing gun electrons that provide all of the significant light output from the DVST and, since it is the major difference between the DVST and the CRT, a discussion of the viewing gun and its operation will answer most questions about storage devices of this type. (See fig. 7–24.)

The heater/cathode combination performs the usual function of emitting electrons, and the screen provides the conversion of electron energy to light energy, its usual function. The less usual parts or functions (fig. 7–24) are as follows:

1. Grid No. 1–Viewing grid No. 1 is unusual in that its major function is not signal insertion or the cutting off of electron flow. The negative field between it and the cathode serves only to shape the electron beam.

2. A2–This grid, sometimes known as grid No. 2, also affects the shape of this electron beam and accelerates the beam toward the screen. However, since this element is common to the "writing gun," it also affects the focus (astigmatism) of the writing gun and therefore



AQ.184
Figure 7-24.–DVST pictorial diagram.

has a very limited operating range unless the mean potential of the writing gun deflection plates is made adjustable.

3. Collimator–This electrode is in the form of a large cylinder through which the diverging electron stream must pass on its way to the screen. The stream is made to diverge (spread out) by adjustment of the grid No. 1 and A2 voltages. This is what is meant in this case by shaping the electron stream. In theory, the collimator, as its name implies, now attempts to influence this diverging electron stream so as to "make parallel" or collimate these diverging electrons. As can be seen from figure 7–24, this element can be made positive or negative with respect to A2 and therefore can create a positive or negative field to accomplish collimation. In actual practice, it is more important to achieve uniform current density than a parallel beam, and this is done by observing the screen for as nearly uniform illumination as possible while adjusting A2, grid No. 1, and the collimator voltages.

4. The collector is an electrode, which consists of a fine wire mesh, tightly stretched, and provides additional acceleration of the collimated beam. Because the collector is a mesh, about half of these electrons will pass through. The remainder will be collected directly by the collector. It has the additional function of collecting secondary electrons emitted by the backing electrode.

5. The backing electrode performs the storage function for the DVST and is often referred to as the "storage grid." Like the collector, it consists of tightly stretched, fine wire mesh, but additionally the back of this mesh is coated with a material which has the property of emitting, on the average, more than one secondary electron for each primary high velocity electron that strikes it. From figure 7–24, it can be seen that the viewing gun electrons that pass through the collector find themselves in a negative field, the backing electrode being a +2 volts. Since their initial velocity is low (only +265 volts from cathode to collector for acceleration), they approach this backing electrode at almost zero velocity. Under the initial conditions shown in figure 7–24, most of the electrons drift through the mesh and are rapidly accelerated by the screen voltage, which can be as high as +10,000 volts.

The viewing gun electrons are now high velocity electrons and, when they strike the phosphor, illuminate the entire screen area (or nearly so if the tube has been previously collimated). If the backing electrode is made negative with respect to the viewing gun cathode, fewer electrons would pass through it, and there would be less light emitted from the screen. If this process is carried on far enough, complete cutoff of light could be accomplished, since all electrons approaching this negative electrode would be turned back to the collector. This can be done by a process called erasing.

A usual value for backing electrode cutoff is about -6 volts, so that any time the side of the backing electrode facing the cathode is between -6 volts and 0, the screen will have some degree of illumination (maximum at 0, minimum at -6 volts). The backing electrode can be considered as a capacitor, with the mesh as one plate and the backing materials as the other. (NOTE: The backing material is a poor conductor or semi-insulator and therefore insulates itself from the mesh while acting as a capacitor plate.)

EQUIVALENT CIRCUIT

The equivalent circuit (fig. 7–25) is a two-dimensional simplified representation of the three-dimensional tube. The electron beam flow is from left to right. The capacitance of the backing electrode is indicated, neglecting the parallel resistance which would indicate the effect of dielectric surface leakage. From figure 7–25, it can be seen that electrons will flow into

AQ.185

Figure 7-25.—Equivalent circuit for erasing operation.

the left-hand plate of the capacitor until that plate is the same potential as the diode cathode, D1, which is 0 volts in this case. The charge on the capacitor is now 2 volts. Electrons from the viewing gun pass through the backing electrode at a maximum density because the backing electrode is at 0 volts on the viewing gun cathode side.

Consider the results if this capacitor were suddenly switched from a +2-volt source to a +8-volt supply. Since the charge on the capacitor cannot change instantaneously, the left side of the capacitor becomes 6 volts positive and viewing gun electrons flow until the charge on the capacitor is 8 volts. If at that time the capacitor is switched back to the +2-volt supply, the left side of the capacitor will be at -6 volts (total charge still 8 volts)–the viewing gun will be cut off, and the screen is dark. Now if the capacitor is switched back to the +8-volt supply, the screen will be illuminated to maximum brightness; and when it is returned to the +2-volt position, the screen will be dark. If the switching is rapid between +2 and +8 (using a multivibrator for example), the light emitted from the screen will assume some average value between maximum (or saturated) light output and 0, depending on the percentage time spent at +8 volts compared to the PRF (duty cycle).

ERASING

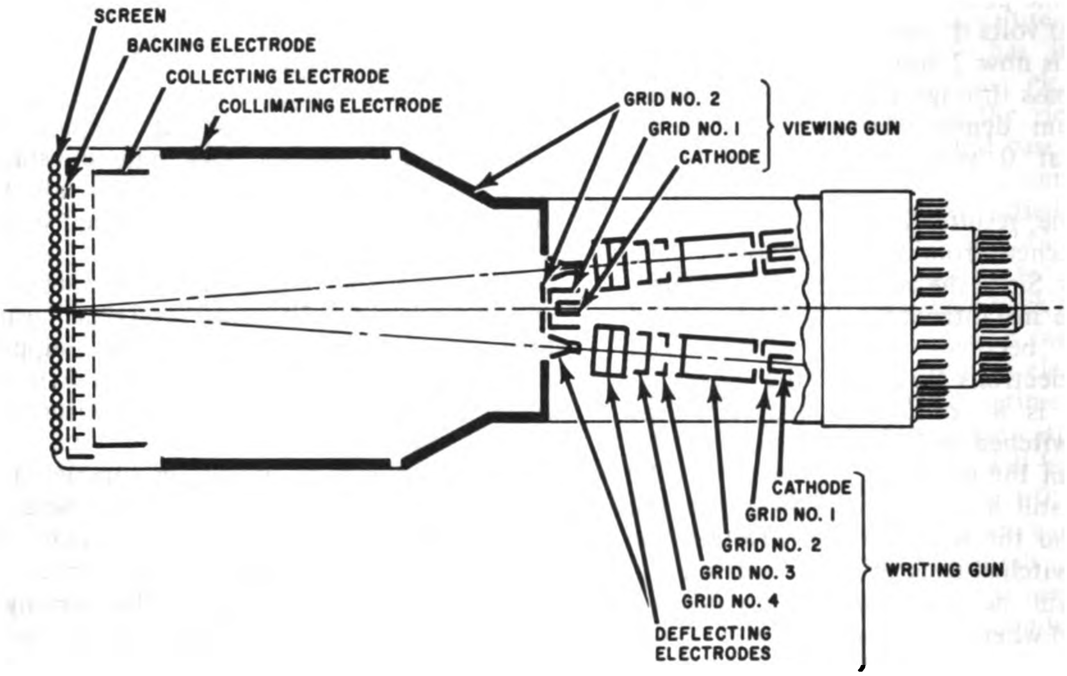
It can be seen from examination of the equivalent circuit that there is no discharge path for this capacitor or backing electrode other than capacitor leakage. This is so because the viewing gun cathode can supply electrons but cannot take them back, hence the reason for including a diode in the equivalent circuit. In theory then, a storage tube could be made, which, once cut off in this manner, would remain cut off for extremely long periods of time (days). In a practical storage tube, however, this cutoff condition can be maintained for several seconds to several minutes, depending primarily on the quality of the vacuum and the storage grid. The apparent storage time can be increased by a process called overerasing which can be done by adjusting the +8 volt supply or pulse to +10 or +12 volts. But this is not a desirable situation in most cases, since it reduces the sensitivity of the tube considerably. (There may be times when it would be desirable to trade sensitivity for increased storage time, however.)

We can also see that, as in the case of any resistor-capacitor combination, a certain amount of time is required to affect the charging of the capacitor. The storage grid time constant is typically 5 milliseconds, and it takes about 10 time constants for complete charging (50 milliseconds) of the storage grid.

This can be accomplished by turning on the +8-volt supply for 50 milliseconds, or it can be done by turning on the +8-volt supply 1 millisecond 50 times or any combination of pulses and pulse widths whose total comes to 50 milliseconds or more.

After this erasure process is completed, the storage grid is ready to accept information to store. This is accomplished by means of a writing gun, identical in every respect to a conventional CRT electron gun. The writing gun supplies a finely focused, high velocity electron stream that can be deflected to any area of the storage grid in the usual manner. Figure 7–26 shows the actual tube construction and the relationship of the writing gun to the viewing gun.

This high velocity electron beam will strike the storage grid and, because of its high velocity, several secondary electrons will be emitted by the storage grid for every primary electron that strikes the grid. These secondary electrons are collected by the collector and the effect is to bring that area of the storage grid out of cutoff. This in turn allows viewing gun electrons to pass through the grid continuously and illuminate the screen. The more primary electrons that arrive, the farther out of cutoff the storage grid will go, up to the point where it tries to become positive with respect to the viewing gun cathode. The presence of viewing gun electrons will prevent the grid from going above cathode potential because, if it did, conduction would bring it back down. Hence it can be seen that a slow scanning, low current density beam will eventually write just as brightly as a high current density, fast scanning beam. In fact, a writing gun which is very nearly cutoff will eventually write to full light output if it is allowed to stay in one spot long enough. Wherever this writing beam hits the storage grid, the grid is moved out of cutoff by some amount, depending on the



AQ.186
Figure 7-26.—Cross-sectional view of a DVST.

current density and the dwell time of the beam; also, where the storage grid is above cutoff, viewing gun electrons pass through the grid and continuously illuminate the screen. It is through this continuous illumination that the high light output is obtained. Otherwise, the light output of a storage tube would be about the same as a convention CRT of similar design. It is this high light output that permits using the display in relatively high ambient light conditions or, if that is not required, permits the use of filters of various types that would attenuate the light of a CRT to otherwise prohibitively low values.

CONTROLLABLE PERSISTENCE

It was mentioned earlier that not only could long persistence of the bright display be obtained but that this persistence was controllable. Let us see how this can be done.

Suppose it is desirable to have approximately 4 seconds persistence. One way in which this could be done would be to "write" for 4 seconds and at the end of that time, apply one 50-millisecond erase pulse. It works, but it is somewhat disconcerting to the operator to receive a burst of full light output every 4 seconds. In addition, the information presented to the operator would not be continuous since at the completion of the single erase pulse the screen would be clean and information would have to be completely rewritten.

A better way would be to supply a chain of erase pulses continuously in such a manner that changing information, being continuously renewed, would decay only slightly between scans of the writing gun. One way to do this is by supplying the waveform to the backing electrode that appears in figure 7-27.

The PRF of this waveform is $(1/4000) \times 10^6 = 250$ pps. Since 50 milliseconds $(50 \times 10^{-3}$

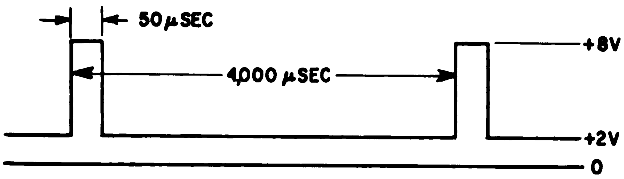


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Figure 7-27.—Erase pulse.

seconds) is required to effect complete erasure, the number of pulses required for erasure is $(50 \times 10^{-3}) \div (50 \times 10^{-6}) = 1{,}000$ pulses. At 250 pps, $1{,}000 \div 250$ or 4 seconds are required to effect complete erasure. Mathematically,

$$\text{Persistence} = \frac{50 \times 10^{-3}}{\text{PRF} \times \text{PW}}$$

$$= \frac{\text{Total time for erasure}}{\text{Portion of erasure accomplished each erase pulse cycle}}$$

The 50 milliseconds is a tube constant which can be different for different tubes and may even vary slightly within tubes of the same type. But it is typical of many tubes in current production. Persistence can be changed at will by changing either the PRF or the width of the erase pulses or both. The amplitude of the pulse must be carefully adjusted to achieve cutoff without overerasure or undererasure. Overerasure results in severe loss of writing sensitivity since small signals will no longer bring the storage grid out of cutoff. Undererasure will mean old information will never be erased from the display area, resulting in smearing and the loss of dynamic range (ratio of smallest signal to largest signal, usually measured in db).

The means for changing persistence to suit conditions are now available. Hence for fast-changing displays, short persistence is desirable so the PRF may be stepped up to 2,500 pps to achieve a 0.4-second persistence. A control could be supplied so that the persistence can be made continuously variable from very short to very long.

SCREEN DAMAGE

By its nature, a storage tube screen is harder to damage by misuse than a conventional CRT. However, some precautions and some peculiarities of the tube should be pointed out.

Where damage to CRT screens results in dark spots due to burned phosphor, similar damage to a DVST results in a bright spot since the burn is usually not on the phosphor but on the storage mesh. This has the effect of "shorting" the capacitor in the area of the burned spot, and that area can never be cut off. To avoid such damage, the writing gun should never be allowed to collapse to a spot and remain stationary for a long period of time. Similar treatment to a CRT results in nearly instantaneous screen damage and, though it takes a little longer with a storage tube, damage will be done. Since the intensity of a storage tube is controlled by varying the screen potential (+10 kv), merely turning down the intensity control will not prevent this type of damage since it only controls screen current. The writing gun bias must be turned down to prevent this type of damage to the storage grid.

Another way to damage the DVST is to write on areas not illuminated by the viewing gun since there would be no supply of viewing electrons to prevent charging the storage mesh up to a destructively high voltage. Since the capacitor is "rated" at 35 volts, breakdown would occur when the voltage exceeds some value near its rating. (A sharp-eyed observer will note that as soon as this potential exceeds the collector potential of +265 volts the secondary electrons will no longer be collected by the collector and further charging toward 2,400 volts would be limited.) Even so, +265 volts would still cause failure.

As was stated earlier, the principal source of light output from the screen is the effect of the viewing gun electrons. Some of the high velocity electrons from the writing guns will pass through to the screen, however, and illuminate it. This illumination is more apparent under some conditions that others (for example, with low screen voltages). The persistence of this "write through" is the same as that built into the phosphor screen and is not controllable. And, because of the geometry of the DVST components, the "write through" may appear slightly displaced from its stored counterpart. Because of its different character (that is, very short persistence, smaller line width, and in most cases lower light output), it is easily distinguished from the stored information and causes little concern unless the operator is not familiar with its cause.

Some of the advantages offered by the DVST may not be so apparent on first examination. Very important is the saving in total weight and size of an indicating system using a DVST.

For example, because the backing electrode is very nearly at ground potential, it forms an effective shield between the writing gun deflection system and the +10,000-volt screen potential. This factor, added to the relatively low writing gun voltage required for proper operation, allows subminiature tubes to be used in the writing gun deflection system. Similar size savings are to be realized in the writing gun power supply.

In addition, because of the characteristics of the backing electrode, it is unnecessary to drive the writing gun grid to zero bias to obtain maximum light output, as in the case with the conventional CRT's. Additional savings in weight, space, and power consumption are to be realized in the design of the video amplifier. Again, subminiature tubes become practical.

As a result, a given indicating system can be packaged so that it is shorter in length, smaller in cross sectional area, and lighter in weight. This requires less primary and secondary power, yet provides target detection enhancement and display brightness that would normally not be possible with conventional CRT devices.

PULSE EXPANSION AND COMPRESSION

Within the past few years, an amazing and powerful radar technique called pulse compression (nicknamed "Chirp Radar") has been incorporated in all types of radars. Pulse compression is possibly the most significant new advance in radar techniques in many years. It can improve a radar's performance by a factor of possibly several hundred. There appears to be no limit in sight to its possibilities. It is finding use in long range search, missile control, fire control, weather observation, aircraft traffic control, mapping radars, and many more. Frequently, computers are used to display the returned target information using standard target symbols rather than displaying conventional video on a PPI type indicator. These symbols depict target position, size, type aircraft, and movement of the target. Generally, the radar is computer controlled.

ADVANTAGES

Some of the advantages which are discussed in this section are extended range with improved range resolution, height finding capabilities, immunity from ECM jamming, and an increased signal-to-noise ratio.

Extended Ranges

One important factor in any radar's maximum range is the envelope power. Envelope power is found by multiplying the pulse width times the peak power. A typical search radar has a pulse width of 2 μsec and a peak power of 2.5 megawatts. This will produce an envelope power of 5 watts/sec. A typical pulse compression radar will have a pulse width of 10 μsec and peak power of 1 megawatt which will produce an enevelope power of 10 watts/sec. Since range is partially determined by the transmitter, this will give us the possibility of an increased range over the conventional pulse radar.

Improved Range Resolution

Range resolution is the minimum distance which two targets must be separated to appear as two separate displays on a scope. This separation is largely determined by the pulse width of the echo being returned to the receiver. In our typical conventional radar with a 2-μsec pulse width, range resolution would be 1,000 feet. In the pulse compression radar, the 10-μsec returned pulse is compressed to 0.1-μsec before being applied to the receiver. Therefore, the range resolution is 0.1 x 500 or 50 feet. This improved range resolution is accomplished without affecting maximum range because the envelope power is not changed.

Height Finding Capabilities

The theory employed by pulse compression to determine height is based on the ability of the radar to receive multiple path returns from a single target. With sufficient power, receiver sensitivity, and range resolution, the system can distinguish between three echo returns. (See fig. 7-28.) By measuring the time difference of the three returns and comparing the altitude of the radar transmitter, the computer can determine the target altitude. Only the pulse compression radar has both the power and range resolution necessary for this type of altitude determination.

ECM Deception

The pulse compression radar depends on the phase and frequency characteristics of the transmitted pulse to determine whether or not to accept a returned signal. If the phase and frequency do not match the transmitted pulse, compression will not take place and the signal will not pass through the receiver.

Signal-to-Noise Ratio

Due to the response of the matched filter to the definite phase and frequency characteristic of the transmitted signal, and the attenuation of other signals, the pulse actually applied to the receiver has a signal content much higher than its content of random noise. The signal-to-noise ratio of the system will be improved by a factor equal to the compression ratio over conventional radar.

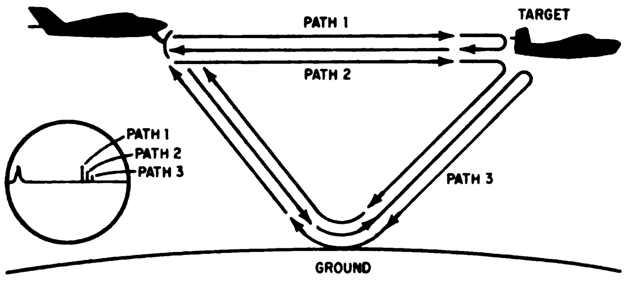

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Figure 7-28.–Multiple echo paths.

Target Velocity

Target velocity can be rapidly determined by the use of a computer and sideband inversion. If a signal receives up Doppler, after sideband inversion the shift will appear as down Doppler. By shifting the local oscillator frequency above and below the returned echo on alternate pulses, the Doppler can be changed from up to down alternately with each transmitted pulse. This will produce a shift equal to twice the normal Doppler shift and will make it possible to determine target velocity in a time equal to two PRT. This principle could be easily incorporated. Sideband inversion is explained in detail later in this discussion.

PULSE EXPANSION

The pulse expansion operation will utilize a 0.1-μsec pulse and expand it to 1-μsec. Then stagger delay (frequency) the 1-μsec pulses to form a 10-μsec chain of pulses for transmission. The overall operation is to generate a 0.1-μsec pulse and, after expansion, transmit a 10-μsec pulse.

Spectrum Generation

RF energy is generated by a Coherent Master Oscillator (COMO) which is gated with a square wave of the desired time duration. For discussion purposes we will use a COMO with a center frequency of 100 MHz which is gated for 0.1-μsec at a PRF of 300 Hz. When this pulse is produced, it contains not only the basic frequency, but also many other frequencies within a spectrum as illustrated in figure 7-29. While the difference between each frequency is determined by the PRF, the pulse width determines the bandwidth and therefore the number of frequencies within the spectrum is controlled by both PRF and pulse width.

In figure 7-29 the frequency which has the largest amplitude is the resonant frequency of the signal source by means of which this spectrum was created. Numerous other frequen-

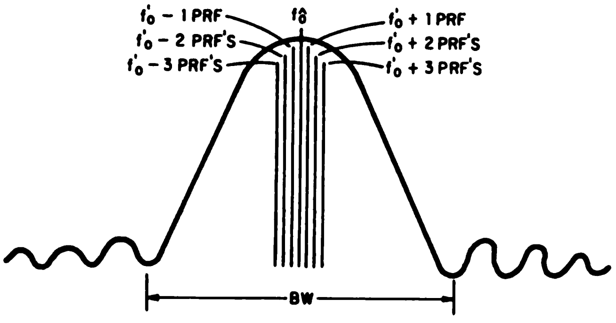

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Figure 7-29.—COMO output.

cies result on either side of f_0. Those above f_0 will be f_0 plus one PRF, f_0 plus 2 PRF's, etc. At this rate, numerous different frequencies are present, each 300 Hz apart, and each smaller in amplitude as these frequencies approach the upper bandwidth limit.

Those below f_0 will be f_0 minus one PRF, minus 2 PRF's, etc. At this rate numerous different frequencies would be present, each one lower in frequency by 300 Hz, and each one lower in amplitude as the lower bandwidth limited is approached.

Since the COMO is gated for 0.1-μsec of time, the COMO will generate a spectrum with a bandwidth of 20 megahertz. Bandwidth is determined by dividing the pulse width into 2. NOTE: In order to receive and to reproduce satisfactorily rectangular pulses equal in amplitude to the noise voltage, the receiver bandwidth in hertz should be approximately 2, divided by the pulse width in seconds. Therefore, a 0.1-μsec pulse width will generate a 20-megahertz spectrum bandwidth. Because each different frequency between the bandwidth is 300 Hz apart, over a 20-megahertz bandwidth, there are 66,666 different frequencies contained in this frequency spectrum.

Matched Filters

For this discussion our matched filter will consist of 10 channels. Each channel will have one or more amplifiers (one of which must be tuned) and a delay line as shown in figure 7-30. Each channel has individual gain and frequency controls with a bandwidth of 1 MHz. The amplifiers are tuned to successive frequencies 1 MHz apart so that their response curves overlap at their half power points as shown in figure 7-31. The entire filter band pass will be 10 MHz from the center of the above described spectrum. The filter will now respond to 33,333 difference frequencies with each channel responding to 3,333 different frequencies. The 10 sections with their respective delay lines are connected with parallel inputs and all outputs connected to a summing amplifier to produce a single output.

The entire frequency spectrum bandwidth (20MHz) is applied to the input of each of the 10 channels through the delay line (all except channel 1 which has no delay line).

Each of the 10 channels is tuned so as to cover only a small part of the total frequency spectrum. Since there are only 10 channels, each with a bandwidth of 1 megahertz, only one-half of the overall spectrum is covered. Therefore, one-half of the spectrum is not passed through the matched filter because it is not within the half power points of any of the 10 channels.

This is necessary because the amplitude of the different frequencies is too great between the maximum and minimum. If the frequencies outside of the channel spectrum halfpower points are rejected, the amplitude difference between f_0 and f_1 or f_2 is now only 3 db. This allows the gain of the channels to be within practical limits.

As was previously determined, the numerous different frequencies within the entire spectrum bandwidth were separated from each other by 300 Hz, and since the overall bandwidth was 20 MHz, there were 66,666 different frequencies. The matched filter is tuned to react to only half of the overall bandwidth, so the filter will receive only 33,333 different frequencies. This is in turn covered in 10 different steps by the 10 filters, so each individual filter will receive only 3,333 different frequencies. For ease of explanation, only 3,300 frequencies will be used in the remainder of this chapter.

EFFECT OF A TUNED AMPLIFIER ON FREQUENCIES WITHIN ITS BAND-

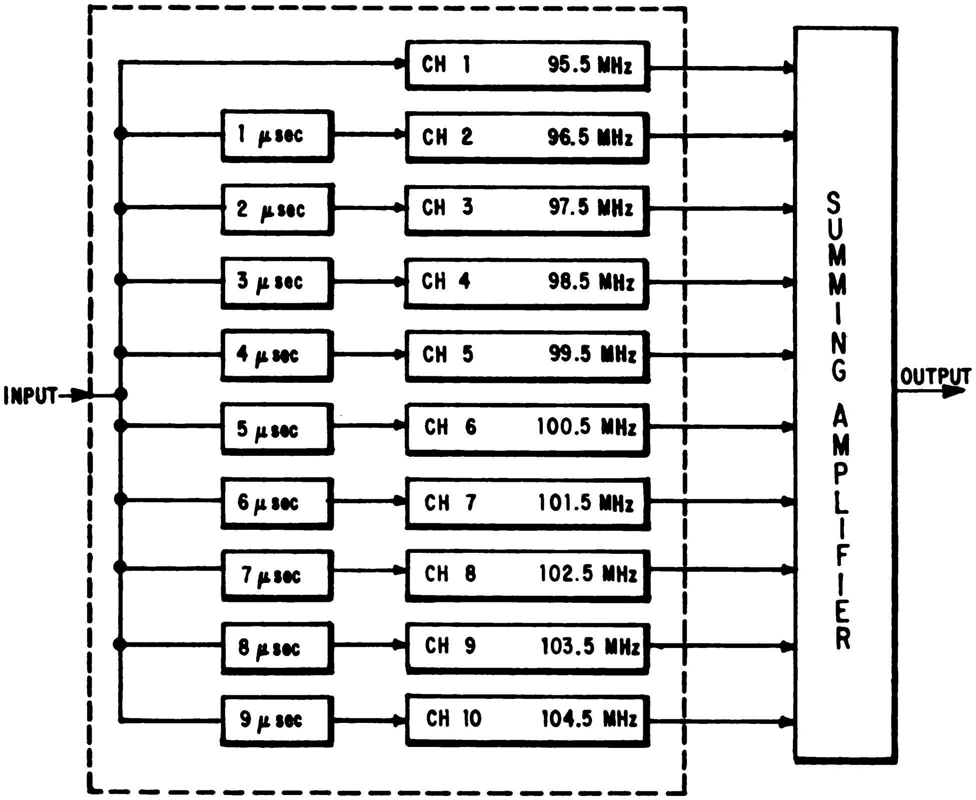

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Figure 7-30.—Matched filter assembly block diagram.

WIDTH.—In a paralleled resonant tank circuit the voltage and current are in phase at f_0. At frequencies below f_0, the circuit appears inductive, X_L, and voltage leads the current. The farther below f_0 the frequency is, the more inductive the tank appears, and the greater lead voltage has over current. At f_1, the voltage leads the current a maximum usable amount.

At frequencies above f_0, the circuit will appear capacitive by the amount that the frequencies differ from f_0. At f_2, the current leads the voltage by the maximum usable amount. Since each tank circuit in the matched filter has a bandwidth of 1 megahertz, and receives 3,300 different frequencies, approximately 1,650 of them will be above f_0, and 1,650 will be below f_0. To those above, the tank will appear capacitive. To those below, it will appear inductive. To the one frequency at f_0 the tank circuit appears purely resistive.

The tuned amplifier is so designed that signal voltages are coupled out rather than signal current. To determine which signal voltages will be developed by the tank, first a reference must be used. This reference is the voltage and current which occur at f_0 of the tank, and which are in phase because the tank is resistive.

The 1,650 frequencies, both above and below f_0, are applied to the tank circuit (tuned amplifier) at the same time. The voltage at the frequency f_1 of the tank will be leading the f_0 current by the amount of X_L that this frequency sees.

Frequencies in between f_1 and f_0 will be leading by a lesser amount because the tank circuit will appear less inductive to these fre-

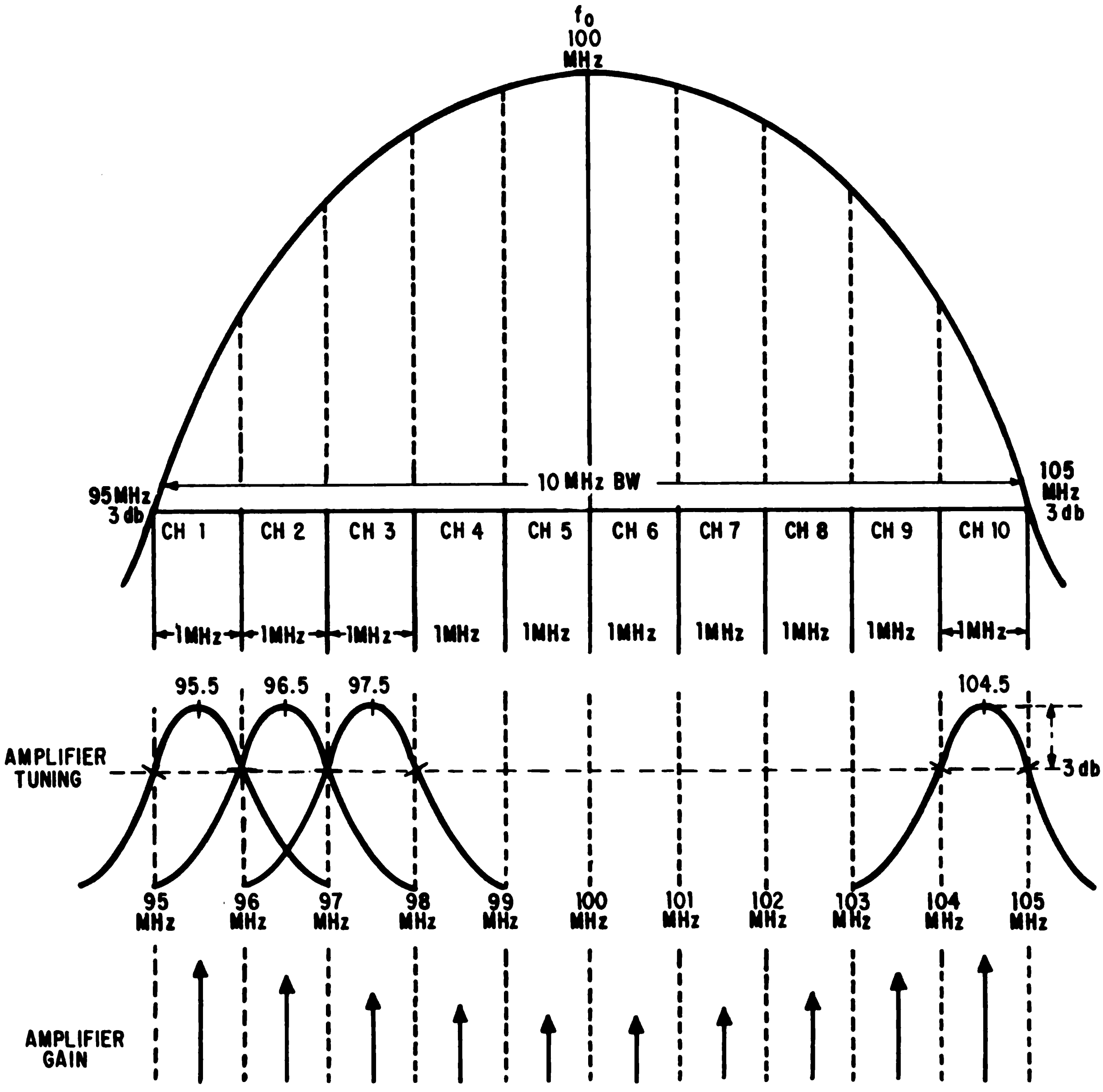

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Figure 7-31.—All channel response curves.

quencies. These voltages will have been advanced in phase (or time) in respect to the voltage at f_0 of the tank.

The voltage of the frequency f_2 will be retarded in phase (or time) because the tank circuit will appear capacitive to that frequency. Before any voltage can be developed, current had to first begin to flow (because current leads voltage across a capacitive circuit). Voltages at frequencies in between f_2 and f_0 saw less X_C, therefore, were retarded less.

The output from this tuned amplifier will be a series of signal voltages at 3,300 different frequencies with the lowest frequency (f_1) occurring first because it was advanced the most in time, and the highest frequency (f_2) occuring last because it was retarded the most in time.

The Q of the tank circuit will be selected so as to advance the voltage at f_1 by 0.5-μsec, and to delay or retard the voltage at f_2 by 0.5-μsec. The time difference between the time when the frequency at f_1 is developed and the time when the frequency at f_2 is developed would then be 1-μsec. Since there are 3,300 different frequencies produced and coupled out of the tuned amplifier in a period of 1-μsec, the time delay between each of these different frequencies is 0.00031 μsec. As shown in figure 7-32, the first frequency to leave the tuned amplifier would be the frequency at f_1 and each 0.00031 μsec thereafter, another frequency would be developed and coupled out until the frequency of f_2 is developed 1 full μsec later.

Since frequency is the reciprocal of time it can be seen that the output from each channel (1 μsec in time) will be 1 MHz wide in frequency.

What has been done is to take 3,300 different frequencies, each one in phase, and time delay or time advance each one by a different amount. This process has created a waveform which begins to appear as a linearly swept FM wave, and is called time dispersion or phase dispersion.

COMBINED OUTPUT OF THE MATCHED FILTER.–As shown in figure 7-30, the entire frequency spectrum is applied to the input of each of the 10 filter channels simultaneously, but through a delay line for channels 2 through 10. This means that channel 1 will receive its input at the instant the spectrum is applied to the input of the filter; however, channel 2 will not receive its input until later in time due to the delay line. Channel 3 will receive its input still later in time than channel 2. This process will continue so that channel 10 will receive its input last because the delay line in its input offers the largest amount of delay.

Channel 1, since it received the frequency spectrum first, will produce an output first. Channel 1 is tuned to 95.5 MHz, and has a 1 megahertz bandwidth, so it will produce in its output only that part of the spectrum from 95 MHz to 96 MHz. The frequency to first appear at the output of channel 1 will be the lowest frequency within the bandwidth of the tuned amplifier. This is because the lowest frequency receives the greatest phase or time advance because of X_L of the tank circuit at that frequency. The last frequency to leave channel one will be the highest frequency within its bandwidth. This frequency receives the most time or phase delay because of X_C of the tank circuit to that frequency. Each of the remainder of the 3,300 frequencies will be either advanced or retarded by a lesser amount, so that the time required for channel 1 to reproduce all 3,300 frequencies will be 1 μsec.

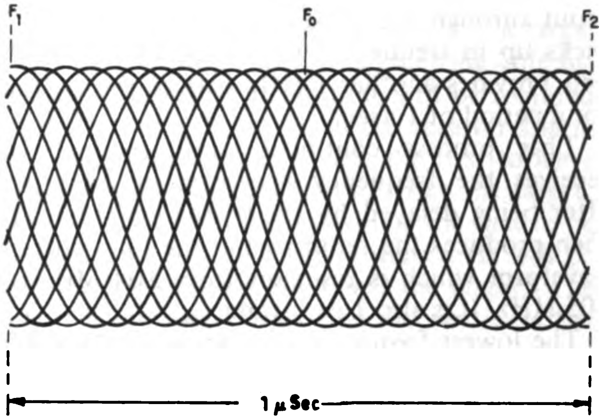

Figure 7-32.–Individual channel frequency output (expansion).

As channel 1 is finishing its output waveform, channel 2 is just receiving the spectrum at its input (because the spectrum was delayed 1 μsec by the delay line). Channel 2 is resonant to 96.5 MHz, has the same 1-MHz bandwidth, and will reproduce that part of the spectrum from 96 MHz to 97 MHz. The lowest frequency within bandwidth of channel 2 will be reproduced first because it receives the greatest advance by X_L. The highest frequency will be reproduced last because it is delayed by X_C. Channel 2 will require 1 μsec to produce its full 1-MHz output. Two μsec in time have now elapsed.

As channel 2 finishes producing its output, channel 3 receives the frequency spectrum at its input through the 2-μsec delay line. Channel 3 picks up in frequency where channel 2 left off and provides another 1-MHz part of the output for a period of 1 μsec.

This process continues until channel 10 receives the frequency spectrum at its input after being delayed by the 9-μsec delay line. It then produces the tenth part of the total output waveform which is resonant from 104 MHz to 105 MHz. It is also 1 μsec wide.

The lowest frequency of channel 1 (95 MHz) is produced, and 10 μsec later, the highest frequency of channel 10 (105 MHz) is produced. This is shown in figure 7-33.

Each of the 10 channels output waveforms will be combined in the summing amplifier to produce the waveform shown in figure 7-33. This waveform sweeps a 10-MHz band of frequencies during a time of 10 μsec with a linear change of 1 MHz/1-μsec. This type of waveform is called a linear frequency modulated pulse. The matched filter which produces this type of waveform is called a LIFMOP filter being coined from Linear Frequency Modulated Pulse. This LIFMOP waveform contains approximately 33,000 different frequencies, each one being in a very definite time and phase relationship to the others.

The output from each channel must be equal in amplitude. To insure equal amplitude from each channel, an oscilloscope is connected to observe the output of the summing amplifier. The amplitude adjustment (screwdriver adjustment) is set on each channel so that the output from each amplifier is equal in amplitude. With the oscilloscope connected to the same point, the frequency adjustment, (a technician's adjustment) is set so that the output of each amplifier coincides with the output of the amplifiers on either side of it with no interruption of the pulse. When any of the amplifiers are changed, both of these adjustments must be performed.

This LIFMOP waveform may be transmitted at these frequencies, or it may be passed through frequency converters to increase the frequency to whatever is desired to be transmitted. It will normally be amplified by several RF amplifiers

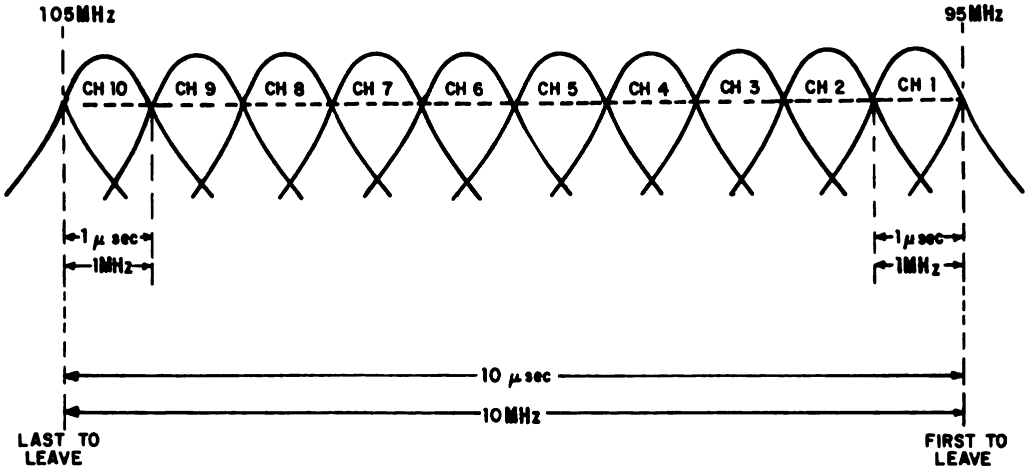

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Figure 7-33.—Summing amplifier output.

prior to being transmitted. These RF amplifiers, of necessity, have a very broad bandwidth and linear frequency response to avoid any type of distortion of the LIFMOP waveform. The waveform shown in figure 7-33 leaves the summing amplifier with some amplitude variations. It is desirable that the transmitted waveform have no variations of amplitude. Normally, the waveform will be passed through a limiter prior to transmit to remove these amplitude variations.

The transmitted pulse will be rectangular, swept in frequency over 10 MHz, and 10 μsec in duration. It is composed of the combined outputs of all 10 filters.

PULSE COMPRESSION

This operation is basically the inverse of pulse expansion. That is, when a 10-μsec target return is received, it is compressed so that the receiver output is a 0.1-μsec echo.

Echo Return from a Target

For discussion purposes assume that a target is located a distance from the receiving antenna so that 100 μsec of travel time will be required for the return echo to reach the receiver antenna. The lowest frequency was the first to leave the transmitter, and the first to strike the target; thus, the lowest frequency will be the first to be picked up by the receiving antenna. (It will be returned 100 μsec after it strikes the target.) The highest frequency transmitted did not leave the transmitter until 10 μsec later. It did not strike the target until 10 μsec after the lowest frequency struck the target. Therefore, it was not returned to the receiving antenna until 10 μsec after the lowest frequency was received. Refer to figure 7-34.

It can be seen that a definite time versus frequency relationship exists during the 10 μsec that the returning echo is felt on the receiver in-

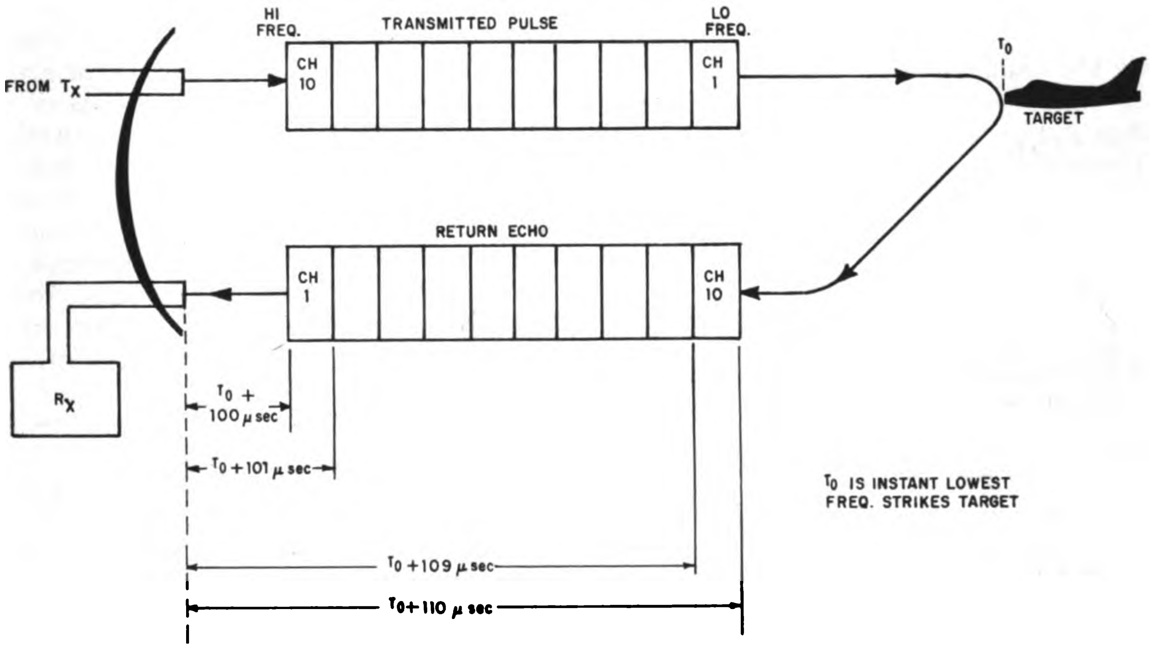

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Figure 7-34.—Time function of transmitted pulse.

put. At any time, the frequency can be determined and, therefore, which channel is receiving a signal. For instance, at T_0 plus 106 μsec, the frequency which will enter channel No. 6 is just arriving at the receiver antenna. This means that the frequencies affecting channels 1 thru 5 have already arrived, and channels 7 thru 10 are yet to come.

If the returned echo is applied to the matched filter as it is now (lowest frequency first), by action of the L and C of the tanks, the filter would tend to expand the signal again, rather than compress it as is desired. For the pulses be compressed, the frequency relationships must be reversed. That is, the returned echo must be turned around so that the highest frequency enters the matched filter first, and the lowest frequency enters last, or 10 μsec later. This is easily accomplished by sideband inversion.

SIDEBAND INVERSION.–Sideband inversion is a process of inverting the frequencies contained in the upper and lower sidebands during the process of frequency conversion. This process occurs any time the local oscillator is tuned ABOVE the frequency to be converted, and the DIFFERENCE frequency is selected. (See figure 7-35.)

NOTE: The reader should be aware that the frequency values used in figure 7-35 are arbitrary values and were selected only to illustrate sideband inversion.

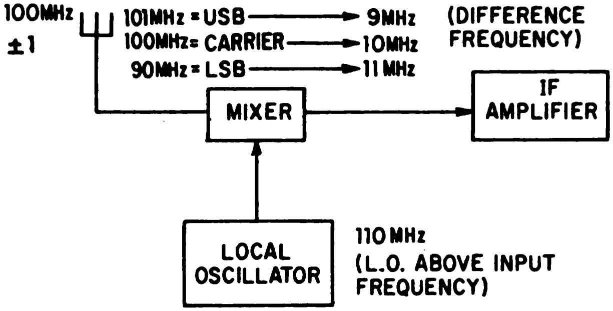

Figure 7-35.–Sideband inversion block diagram.

From figure 7-35, it can be seen that when the upper sideband (101 MHz) passes through the mixer, the difference frequency produced is 9 MHz. When the lower sideband frequency (99 MHz) is converted, the difference will be 11 MHz. Thus, the highest incoming RF produces the lowest difference frequency, and the lowest RF produces the highest difference frequency. In the case of the pulse compression radar under discussion, the returned echo is passed through a frequency conversion stage for the purpose of sideband inverting the frequencies. The lowest frequency which was first returned will become the highest frequency after sideband inversion (95 MHz will emerge as 105 MHz). The highest frequency (105 MHz) returning last will emerge from the mixer as 95 MHz because of this process, the entire frequency content of the returning pulse will be reversed. After this inversion, the echo is now ready to be applied to the matched filters for pulse compression.

Action of Matched Filter on the Returned Echo

The returning pulse, AFTER SIDEBAND INVERSION, is once again applied to the paralleled inputs of all 10 matched filter channels. The difference between the input to the matched filter, now on the pulse compression function, and the input for the pulse expansion function on transmit is that on pulse expansion, ALL frequencies (each one in phase) were present at EACH channel at the SAME TIME. But on pulse compression (or receive), the frequencies arrive ONE AT A TIME, each one separated from the others by a small phase and time difference. The first frequency to arrive, at T_0 plus 100 μsec, is the highest input frequency to the filter after conversion, and 10 μsec later, at T_0 plus 110 μsec, the lowest input frequency after conversion arrives at the filter. It must be noted that as each individual frequency arrives, it is present at the input to each one of the 10 channels simultaneously.

The highest frequency (after conversion), being the first to arrive, is applied directly to the matched input filter. Since this frequency is within the bandpass of ONLY channel 10, it will affect only channel 10. Before it can be applied to the tuned amplifier of channel 10, it receives a 9-μsec delay. Therefore, this frequency finally is present at the tuned amplifier of channel 10 at T_0 plus 109-μsec. For the next 1-μsec of time, all of the frequencies within the band pass of channel 10 will arrive and be processed. The highest frequency (105 MHz) at T_0 plus 109 μsec, is above the resonant frequency of channel 10 (104.5 MHz), so the tank circuit appears capacitive to that frequency.

The tank circuit has the same effect on frequencies ABOVE its resonant frequency that it had previously during pulse expansion–that is, it will delay these frequencies by an amount proportional to the amount of capacitive reactance the tank offers to that frequency. The 105-MHz signal, being the farthest away from the f_0 of the tank, will be delayed the most (approximately 0.45-μsec).

The next frequency to arrive at the tank is slightly later in time and lower in frequency, and receives slightly less delay than did 105 MHz. When 104.5 MHz arrives (at T_0 plus 109.5 μsec), the tank simply passes it exactly as it is. The rest of the frequencies within the bandpass of channel 10 are lower than the f_0 and sees an inductive reactance. This advances these lower frequencies by an amount proportional to the X_L of the tank. The 104 MHz signal, the lowest frequency within channel 10's bandpass, sees maximum inductance and is advanced approximately 0.45-μsec. The end result is that the bandwidth of frequencies of channel 10 (which was 1 μsec wide) is compressed to 0.1-μsec, and comes out of channel 10 at T_0 plus 109.45-μsec to T_0 plus 109.55-μsec. This is shown in figure 7-36.

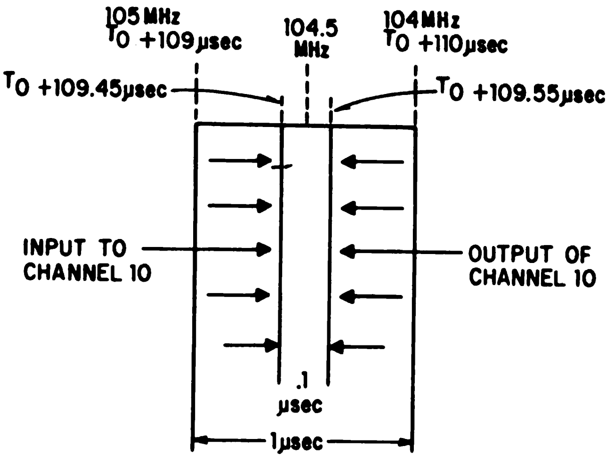

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Figure 7-36.—Individual channel compression.

The band of frequencies processed and compressed by channel 10 arrived at the receiver antenna from T_0 plus 100-μsec to T_0 plus 101-μsec. From T_0 plus 101 μsec to T_0 plus 102-μsec, the frequencies within the bandwidth of channel 9 will be arriving at the receiving antenna. To get to the tuned tank of channel 9, they must pass through the 8-μsec delay line. Then, at T_0 plus 109-μsec, the first frequency for channel 9 (104 MHz) will arrive. This frequency is higher than the resonant frequency (103.5 MHz), so it will be retarded approximately 0.45-μsec, and will be reproduced in the output of channel 9 at T_0 plus 109.45-μsec. The lowest frequency to channel 9 (103 MHz) sees maximum inductance and will be advanced approximately 0.45 μsec. Channel 9 will produce its output from T_0 plus 109.45 μsec to T_0 plus 109.55 μsec, or during the same time channel 10 was producing an output.

This process continues as each one of the channels receives its band of frequencies 1 μsec apart in time, but produces its output at the same time as each of the other channels. Finally, at T_0 plus 109-μsec, the first frequency to pass through channel 1 arrives at the receiving antenna, and is felt directly on the tuned tank in channel 1 since channel 1 has no delay line. Channel 1 then produces an output at the exact same time as the previous nine channels.

COMBINED OUTPUT OF THE MATCHED FILTER.–The output circuit of each individual channel is fed into summing amplifiers where all 10 outputs are combined. Because each channel produces an output at exactly the same time, and for exactly the same time duration, all 10 outputs add directly, and appear at the output of the summing amplifiers as one pulse 0.1 μsec in duration. The entire 10-μsec return echo has been compressed to 0.1-μsec, and is now ready to be detected and sent to the indication devices.

The ratio between the pulse width of the transmitted pulse and the returned compressed target echo is expressed as the compression ratio. It is determined as follows:

$$\text{Compression ratio} = \frac{\text{pulse width of expanded pulse}}{\text{pulse width of compressed pulse}}$$

The compression ratio of the radar being discussed is:

$$\text{Compression ratio} = \frac{10\text{-}\mu\text{sec}}{0.1\text{-}\mu\text{sec}} = \frac{100}{1} = 100:1$$

This expression is considered a figure of merit for a pulse compression type radar.

During this process of pulse compression, some apparent amplification occurs across the matched filter. This is because of the energy content and time duration of the returned echo. The 10-μsec pulse arrives with a certain volt/amps energy content, but it is compressed in time down to a pulse of 0.1-μsec. Assuming none of the energy content was lost across the matched filter, the same amount of energy must still be present in the compressed pulse. If the pulse width narrows, the amplitude of the compressed pulse will increase. This increase is the same as the compression ratio. In the radar under discussion, the pulse is compressed by a ratio of 100:1, so the amplitude of the compressed pulse is 100 times larger than the amplitude of the received target return, and still contains the same energy content.

It must be noted that in a practical radar using pulse compression, it is very difficult to get the returned energy compressed back to the same pulse width that was used in the pulse expansion sequence. As previously stated, there are many thousands of frequencies, each different by one PRF, in the transmitted pulse. Each of these frequencies bears a very definite time/phase relationship to each other. To compress the returning echo back to the original pulse width, each one of the frequencies must be present, and must still bear the exact same time/phase relationship that it did upon leaving the transmitting antenna. Due to atmospheric conditions and waveguide vibration, some atmospheric modulation occurs between pulse expansion and pulse compression. Some of the frequencies will be changed, so it will not be easy to reconstruct the original pulse. In the radar under discussion, typically the 10-μsec returned echo is compressed into a 0.2-μsec pulse, for a compression ratio of 50:1. This means that if the entire energy content is maintained across the filter, the amplitude of the compressed target video would be 50 times larger than the amplitude of the returning echo.

SIGNAL-TO-NOISE RATIO

The noise which might exist in the band of frequencies covered by the radar are at random frequencies and bearing random phase relationships to each other, and to the returning target echo. Any of these frequencies which exist within the bandpass of the matched filter passes through the filter, but are not affected by the filter. That is, they are neither expanded nor compressed because of their random relationship, so they emerge at the same amplitude at which they went in while the return echo emerges enlarged in amplitude by the amount of the compression ratio. Radars using pulse compression are generally considered to have an increase in the signal-to-noise ratio across the matched filter approximately equal to the compression ratio. This is in addition to the signal-to-noise ratio increase which might be gained by using suitable receiver input amplifiers.

ECM CONSIDERATIONS

As was previously stated, it is very difficult to jam a pulse compression type radar. This is primarily because of the characteristics of the matched filter. To overcome the target video, noise jammers would have to produce enough noise signal so that the noise at the receiver antenna would be greater than the returning target echo by the amount of the compression ratio. This is easily eliminated by insertion of circuits between the antenna and matched filter which automatically reject abnormally large signals. This method is currently in use in certain long range search radars in operation with the fleet. Repeater jammers, to override the actual target return, would have to generate a spectrum containing exactly the same frequencies, each bearing the exact same phase and time relationships as that of the transmitted pulse. Even if this were possible (some types of ECM equipments simply amplify whatever their antennas receive), the ECM signal would be rejected since it would be larger in amplitude than the valid received target return. This repeater jammer could have no more delay between the time it received the transmitter's signal and the time that it retransmitted this same amplified signal than the time duration of the compressed pulse as it comes out of the matched filter. When the delay is greater than the pulse width of the compressed pulse, the indication device (computer) would see two distinct returns. One would be the target, and the other would be the ECM signal. Even if the delay was less than the pulse width of the compressed pulse, the computer would still see the target return first, then a sudden increase in amplitude as the ECM signal came through. The computer would automatically reject ECM return, but would see the target return. Chaff jamming is easily countered by the incorporation of circuits which reject abnormally slow moving targets such as chaff, corner reflectors, balloon borne devices, etc.

To further increase the difficulty in jamming the pulse compression type of radar, the PRF could be made to vary at a random rate. This will cause each and every frequency in the transmitted pulse to change slightly each time the transmitter fires. Unless the returning echo contains exactly the same frequencies that were just transmitted, the matched filter will reject them.

CONTINUOUS WAVE DOPPLER MTI

The basic continuous wave (CW) Doppler moving target indicator (MTI) radar detects moving targets in areas or regions of heavy clutter, down to zero range. The moving targets, which are detected, are those having changing range rates. Crossing targets (moving targets not having a changing range rate) are not detected.

OPERATION

The operation of a CW Doppler MTI radar relies on the phenomenon that a moving target changes the frequency of the transmitted signal. The difference in frequency between the transmitted signal and the returning signal is termed the doppler frequency. The usefulness of the CW type Doppler radar is limited because the range of targets cannot be determined.

A block diagram of a basic CW Doppler MTI radar circuit is shown in figure 7-37.

The radar system transmits a CW signal from the radar antenna to a moving target. The fact that the target is moving causes the signal to be changed in frequency with respect to the transmitted signal. This change in frequency of the returned signal produces a constantly changing phase relationship with the transmitted signal. A nonmoving target will produce a fixed phase difference between the two signals, but a moving target will cause a constantly changing phase difference. This provides the means of distinguishing between moving and fixed targets.

The returned signal is received by the receiving antenna, and together with a sample of the transmitter signal, is applied to a phase detector. In the phase detector, the phase of the received signal is compared to the phase of the transmitted signal to produce a resultant output.

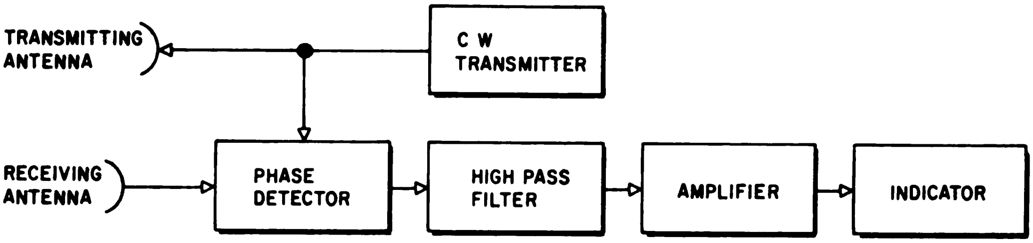

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Figure 7-37.—Basic CW Doppler MTI radar circuit block diagram.

Nonmoving targets have a fixed phase difference and therefore produce a constant, or d-c, output. The constantly changing phase difference in the signal of a moving target will produce an output which is constantly changing, or fluctuating.

The high-pass filter rejects the d-c components of the video that represents stationary targets and passes the video fluctuations produced by moving targets. The fluctuating signals are then amplified and applied to an indicator as MTI video.

PULSE-MODULATED DOPPLER MTI

The pulse-modulated Doppler MTI radar detects one or a multiplicity of moving targets in the heaviest of ground clutter, and can be used to measure the velocity and range of targets. Crossing targets are nonmoving as detected by this type MTI.

OPERATION

The pulse-modulated Doppler MTI radar circuit uses filters to remove stationary targets in the same manner as in the basic CW Doppler radar circuit. However, the CW Doppler radar can function to zero range whereas the pulse Doppler radar cannot. The pulse-modulated Doppler radar can be used in areas that normally produce heavy ground clutter, and is useful for measuring both target range and velocity. The pulse Doppler method imposes no restriction on the relative values of either Doppler or recurrence frequencies.

An undesirable effect inherent in MTI is when the Doppler frequency is equal to a multiple or submultiple of the transmitter frequency. In this case, the resulting signal is unchanging in either amplitude or polarity, and the moving targets producing these multiple frequencies will be eliminated the same as a stationary target. The radar system is said to be blind to targets moving at this speed; these speeds are called "blind speeds".

A block diagram of a typical pulse-modulated Doppler MTI radar is shown in figure 7-38.

The radar oscillator produces the transmission carrier frequency (f_0) and applies this frequency to both the modulator and second mixer circuit. The modulator produces the transmitter pulses which pulse-modulates the carrier frequency, and triggers the transmitter which allows transmission of the signal.

The returned signal pulse (f_0), plus or minus the Doppler signal (f_d) from any moving target, is received by the antenna and applied to the input of the mixer via the waveguide. In the case of incoming targets, the Doppler frequency (f_d) is added to the returned signal; for outgoing targets, (f_d) is subtracted from the returned signal. The resulting signals are then fed to the first mixer circuit.

The second mixer circuit, which receives the transmission carrier frequency (f_0), also receives a signal from the 30-MHz oscillator. These signals are mixed and the lower sideband (difference frequency) is passed and applied as f_0 - 30 MHz to the first mixer circuit. In the first mixer, f_0 - 30 MHz is mixed with the received signal ($f_0 \pm f_d$). The resultant output frequency (30 MHz $\pm$ f_d) is applied to the IF amplifiers. The amplified output is detected and applied to the clutter filter as nonfluctuating video for nonmoving targets, and fluctuating bipolar video for moving targets. The clutter filter suppresses by frequency rejection, the clutter signals not having the video frequency responses of either moving or almost nonmoving targets.

The noise and Doppler filter network provides additional filtering of target video to remove the undesirable video responses.

The limiter-differentiator network removes excessive amplitude peaks of the signal, and differentiates the pulse. The differentiated pulse is then presented on a CRT indicator for display.

COHERENT MTI

Coherent MTI responds mainly to moving targets. Only the moving targets having changing range rates are selected for presentation on an indicator, normally an A-scope.

OPERATION

Unlike the basic CW Doppler or the pulse-modulated Doppler circuits which use filters to eliminate stationary targets and clutter, the coherent MTI detects the difference in phase between the echo signal and a reference signal

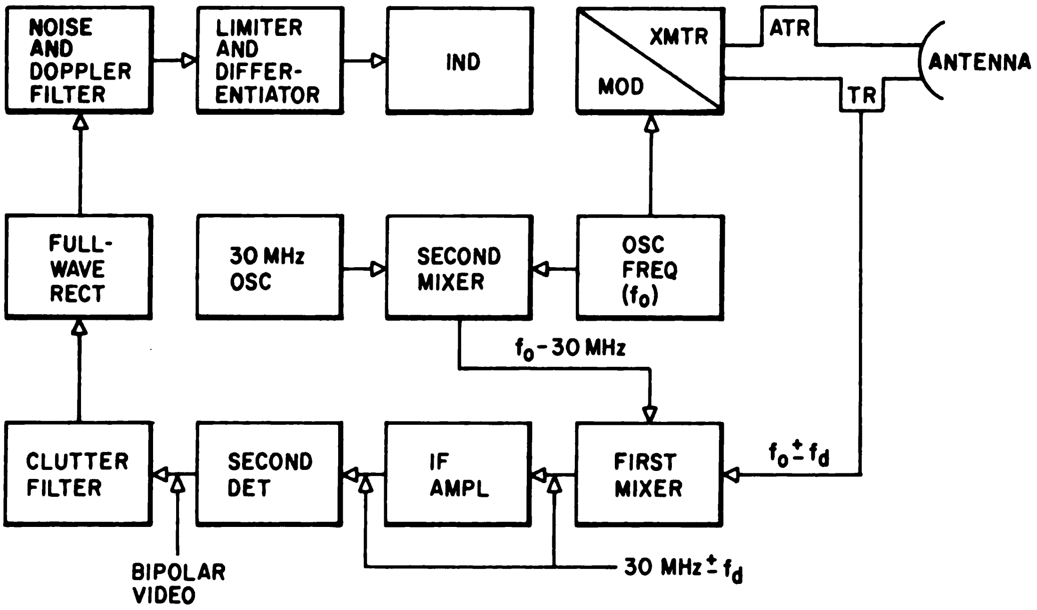


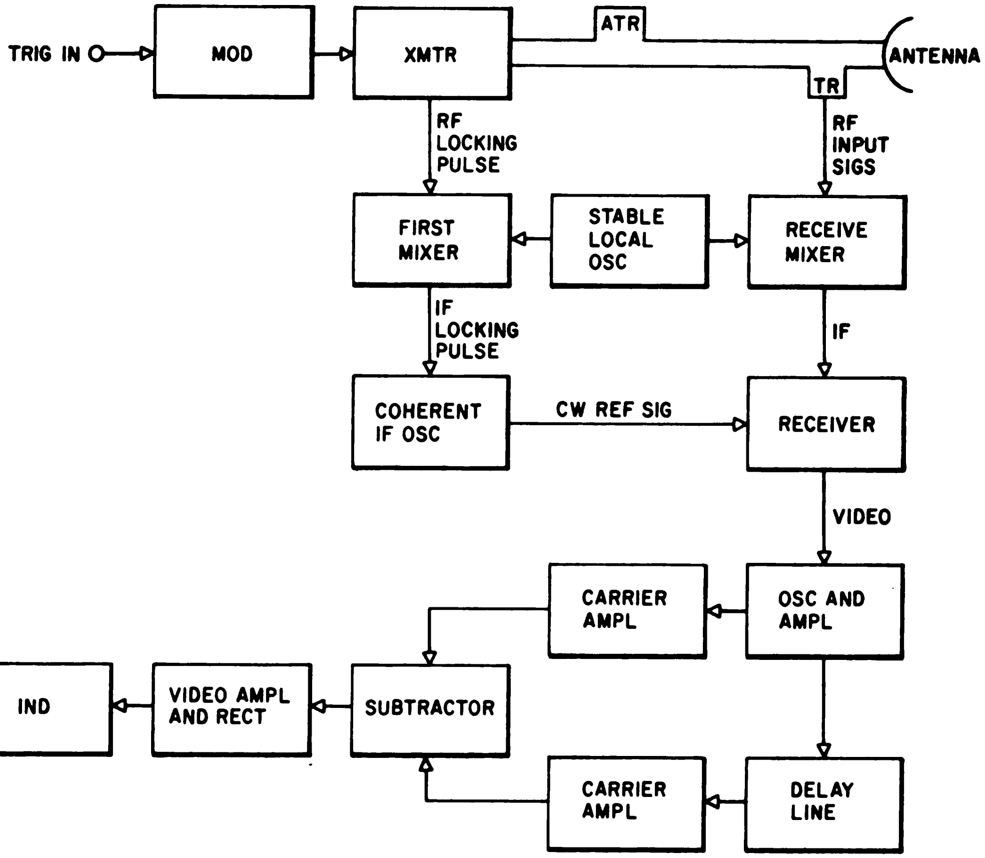
Figure 7-38.—Pulse-modulated Doppler MTI radar block diagram.

whose phase is in step with the transmitted signal. The phase of the echoes from moving targets changes from pulse to pulse, and when beat against the reference signal, a change in amplitude of its detected video occurs from pulse to pulse. Nonmoving targets produce detected outputs having relatively equal amplitudes from pulse to pulse, because their phase does not change from pulse to pulse. A cancellation circuit is then used to remove the nonfluctuating video of nonmoving targets and pass the fluctuating video responses for display of only the moving targets.

A block diagram of a typical coherent MTI circuit is shown in figure 7-39.

The coherent IF oscillator, commonly called COHO for coherent oscillator, provides a CW reference signal with which to beat the received echo signals. Since the transmitter starts with random phase from pulse to pulse, it is necessary to match the phase of the COHO to that of the transmitter at each transmitted pulse. This is accomplished by sampling the transmitted signal (RF locking pulse) and using it (after conversion to the IF locking pulse) to control the phase output of the COHO. (This process is called "locking" the phase of the oscillator, or making it "coherent." Likewise, the IF of the received echo signals must be locked in phase if their phases are to be in step with the transmitted signal. This is the purpose of the stable local oscillator and first mixer combination. Any change in phase of the echo IF, as a result of a phase change from the stable local oscillator, is also reflected in the IF locking pulse. The overall result is an echo IF coherent in phase with the CW reference signal from the COHO, but only if the echo IF was produced from a nonmoving target. A moving target changes the phase of the transmitted signal which results in a change in phase of its echo signal. These phase changes are out of step with the phase of the CW reference signal, and cause a change in amplitude when detected as video in the receiver.

The detected pulses from the receiver are applied to modulate the frequency produced by an oscillator. This oscillator produces a carrier frequency (normally about 15 MHz) to which



AQ.42
Figure 7-39.—Coherent MTI radar block diagram.

the delay line crystal is resonant. The newly modulated carrier is amplified and then applied to two separate channels. One channel consists of the delay line, carrier amplifier, diode detectors, and video amplifier. The other channel is identical, except it has no delay line.

A pulse, ready for transmission, is delayed one pulse repetition time so that it can be compared with the returning echo resulting from transmission of a previously transmitted pulse. The next pulse is delayed for comparison with the third pulse, etc. The cancellation network consisting of the two channel circuits functions as a unit. Channel one, containing the delay line, accepts the new carrier signal pulse-modulated by the echo signal. After being delayed by the mercury delay line, this signal is applied to the carrier amplifier. Following amplification, the signal is detected and rectified, and the output appears across a resistive network. Channel two, without the delay line, accepts the new carrier signal pulse-modulated by the transmitter pulse, and immediately amplifies the signal. Following amplification, the undelayed signal is detected by a diode which is opposite in polarity to the detector of channel one, and the carrier frequency is removed. The output signal appears across the same resistive output network as the output from channel one, but with opposite polarity. Thus the two detector outputs are applied in opposite polarity to the same resistive output load.

The algebraic addition of these two signals provides zero output for a stationary target but yields an output signal for a moving target. The moving target signal is applied to a video amplifier, and following amplification, is applied to a rectifier circuit, because the signal from a moving target is bipolar. The rectified signal is applied to the indicator for display.

CHAPTER 8

TYPICAL AIRBORNE MISSILE CONTROL SYSTEM

The purpose of this chapter is to provide information on a typical airborne missile control system. The Aviation Fire Control Technician is primarily concerned with missile guidance and control equipment installed in the aircraft. The missile itself contains guidance and control equipment which is not necessarily a matter of concern for the AQ; however, it is essential that he have a basic understanding of the fundamentals of missile guidance and control relative to the missile itself.

FUNDAMENTALS OF MISSILE GUIDANCE AND CONTROL

To have a better understanding of the problems involved with effectively directing a missile to the target, the technician must become familiar with the fundamentals of missile guidance and control. Guided missiles differ from gun and rocket projectiles in that gun and rocket projectiles are committed to a given course at the instant of firing, while the course of a missile is altered during flight. The missile fire control problem must be continuously solved. To accomplish this, the four functions which must be performed are as follows: (1) tracking; (2) computing; (3) directing; and (4) steering.

The necessary components for the performance of all the functions may be located entirely within the missile itself, or some may be located in the launching aircraft. It should be apparent that the Aviation Fire Control Technician is primarily concerned only with those components located in the aircraft.

A precise comparison between the gun and rocket fire control problem and the missile fire control problem is difficult to make. In naval aircraft, the gun and rocket fire control problem is continuously solved from the start of the run until the projectile is fired; but the solution of the missile fire control problem continues until the missile strikes the target.

MISSILE FIRE CONTROL PROBLEM

There are three phases to the missile fire control problem; namely, prelaunch aiming, guidance, and control. Together they determine the proper flightpath for the missile and control the missile so that it follows this path.

Prelaunch Aiming Phase

The prelaunch aiming may be considered to be similar to the aiming problem for unguided weapons (guns and rockets), but with a wider tolerance for aiming errors. It might also be considered to be an essential part of the guidance phase.

Guidance Phase

The guidance phase of the missile fire control problem is concerned with that portion of the problem which determines the missile's course to the point of interception. The guidance system must perform three functions—tracking, computing, and directing. (NOTE: Guidance in semiactive homing usually involves the use of radar and computing equipment necessary to determine how a missile's course must be changed to intercept the target.)

Tracking is the process of continuously determining the relative positions of the target and the missile. Tracking may be done by visual observation, the use of radar, or any other process which utilizes some distinguishing feature of the target. The tracker may be located in the missile itself or in the launching aircraft.

Computing is the process of determining course corrections, both magnitude and direction, which the missile must make to score a hit. The computing system may be elaborate or simple, but all systems utilize tracking data received from the tracking system. The computing equipment may be installed in either the missile or the launching aircraft.

Directing, as the term implies, is the process of directing or telling the missile what course corrections must be made. The output of the computing system furnishes correction data which is transmitted to the missile's control system, to accomplish steering. A computing system, located in the launching aircraft, must transmit course correction data to the missile. Radio waves are normally utilized to complete the data transmission loop.

Control Phase

The control phase is concerned with the performance of the steering function previously mentioned. The steering function deals with the aerodynamic portion of the missile fire control problem which, when properly performed, provides smooth and stable flight of the missile. The steering function is performed by the control system consisting of equipment required for converting steering or guidance signals to movement of the missile's control surfaces. The control system is contained entirely within the missile itself and is of little concern to the Aviation Fire Control Technician except to provide a better understanding of the overall system.

METHODS OF GUIDANCE

In operations involving air to air missiles, the target is usually located a short distance from the launching platform when compared with the surface to surface missile operations. In most cases the target is also relatively small and highly maneuverable. Therefore, a guidance method is required that is capable of making continuous corrections to the flightpath and which can respond rapidly to changes in the position of the target. The guidance systems must be suitable for use with maneuverable launchers, since air launched missiles are carried either on pylons attached to the wing or fuselage or on some enclosed or retractable mechanism.

The guidance methods most suitable for these conditions are the visual target acquisition system (VTAS), the beam rider, and homing.

VTAS Method

VTAS enables a pilot or crewmember to aim an AIM-9 Sidewinder missile merely by turning his head and looking at a target. This is accomplished by a small retractable glass reticle mounted on the helmet that snaps down in front of one eye, two infrared sensors also mounted on the crewmember's or pilot's helmet, and two beams of infrared light emitted from two sources mounted in the cockpit aft of the pilot's shoulders. (See figure 8-1.)

The two infrared sources produce two fan-like beams that rotate at a constant velocity. When the difference in their time of arrival at the two infrared sensors are compared with the arrival of a fixed reference sensor, the azimuth and elevation position of the helmet is found and converted into azimuth and elevation angles by a digital computer, which is also part of the system.

Therefore, the pilot or crewmember need only look at the target and the elevation/azimuth look angles are transmitted to the Sidewinder missile's guidance head.

Beam Rider Method

In the operation of the beam rider method the target is tracked by a radar beam (usually that of a radar set carried by the launching aircraft), and the missile responds to the beam by means of a receiver. The output of the receiver consists of error signals which, when applied to the control system, cause the missile to remain in the center of the radar beam until it collides with the target. Figure 8-2 illustrates the beam rider guidance method.

Missiles controlled by the beam rider method are subject to direct control by the launching aircraft radar. Once the target has been acquired by the aircraft radar, automatic tracking devices

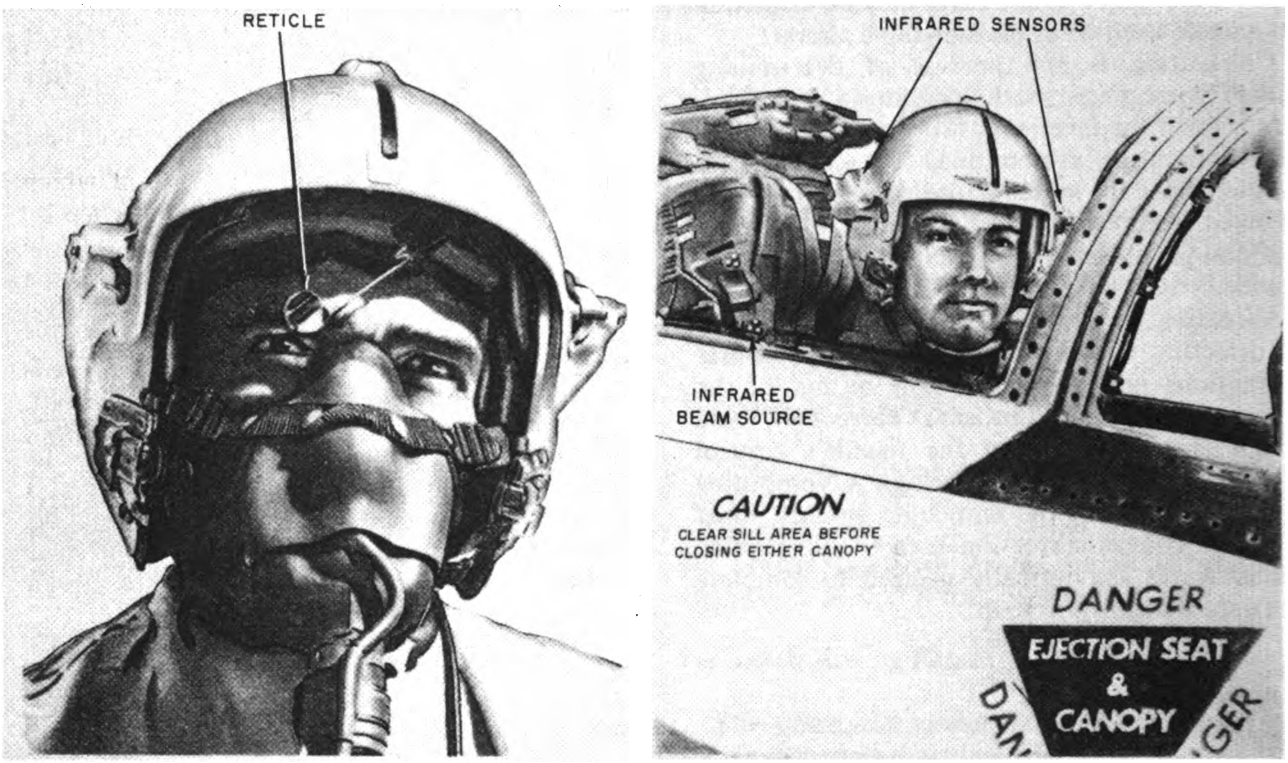


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Figure 8-1.—Visual target acquisition system.

keep the radar beam continuously on the target. An automatic homing device may also be used to control the missile during the final stage of its flight.

Homing Method

With the homing method of guidance, the path of a missile can be changed, after launching, by a device in the missile that reacts to some distinguishing feature of the target—such as heat, light, or reflection of radar waves. A homing device, usually placed in the nose of the missile, picks out the target and then directs the missile to the target.

The best homing systems make use of heat radiation and reflection of RF energy. These systems are accurate, and the missile may be expected to hit its target if released within its range of operation.

Homing guidance systems are of three types—active, passive, and semiactive. In the active homing guidance system, both the transmitter, which illuminates the target, and the receiver, which receives the echoes, are carried within the missile. In the passive system, the missile utilizes radiations from the target. With the semiactive system, the receiver in the missile utilizes radiations from the target, which has been illuminated by a transmitter located in the launching aircraft.

There are several ways in which the missile's homing device may control the path of the missile to a moving target. The more generally used systems are the pursuit homing and lead homing types, in which the course flown by the

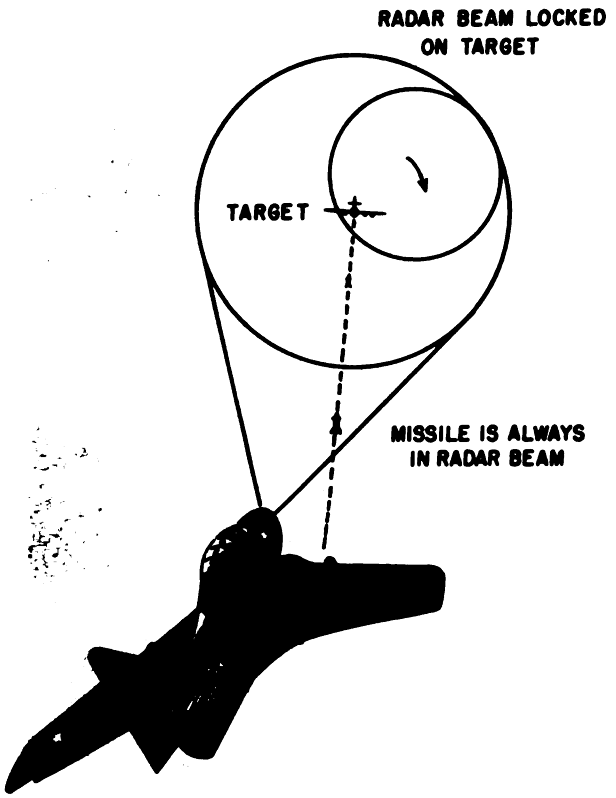

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Figure 8-2.—Beam rider guidance method.

missile approximates that of a lead collision course.

In pursuit homing, the guidance system causes the missile to point directly toward the target at all times. The homing device points directly ahead and keeps the heading of the missile the same as the direction of the target echoes. A missile flying pursuit course experiences increasingly large "G" forces due to turning in the last portion of the course, as shown in figure 8-3. This part of the flightpath is most critical; and unless the target is either large or flying a collision course, accuracy is greatly reduced. As a result, pursuit homing does not have many applications against high speed targets.

In a lead homing, a lead collision course is established when the path of the missile maintains a constant angle with the path of the target. In lead homing, the guidance system establishes a lead angle with the target and keeps this angle essentially constant so that the missile travels directly toward a collision point, as shown in figure 8-4. This causes the missile to complete the final and critical part of the flightpath as a straight line.

To effect this course it is necessary for the guidance system to measure the rate at which the angle changes. This may be accomplished by having the homing device point toward the target; and any change in the direction of the target from the missile will cause the homing device to turn. The rate at which it turns can be measured by a rate gyroscope. These additional functions require that the homing system for a lead course be more complex than a system for a pursuit course.

One of the main limitations of homing systems is that of range. Also, homing devices must have high directional sensitivity so they will not be confused by multiple targets. Because of these problems, it is necessary to place the missile in the vicinity of the target and pointing toward the target. This may require the initial part of the course to be controlled by another type of guidance system, such as the beam rider system.

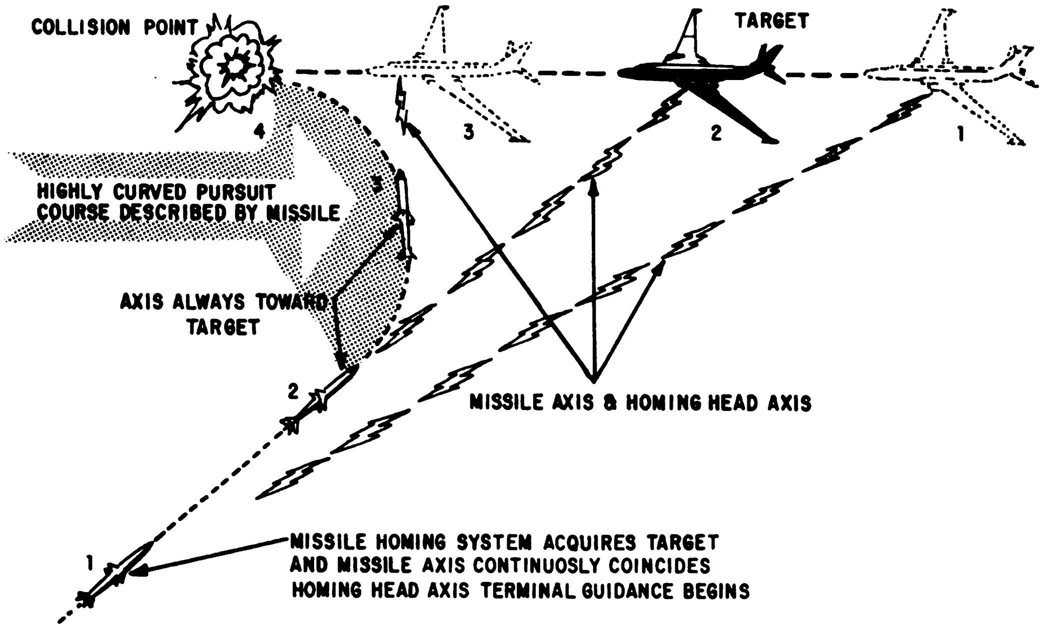
A TYPICAL MISSILE CONTROL SYSTEM

The primary purpose of the airborne missile control system (AMCS) is to assist the pilot in carrying out attacks against enemy aircraft with a high probability of success under all environmental conditions. The intercept problem posed by this type of mission requires that the system enable the pilot to navigate to the target area, find and identify the target, acquire the target, and track it throughout the attack. The system must present steering information to the pilot by means of a radar indicator.

A typical missile control system capable of solving the missile fire control problem consists primarily of two items:

1. An intercept system consisting of an intercept pulsed radar and a computer group.
2. A CW radar group.

Additional components may be required to make up the complete system; for example, a


COLLISION POINT
TARGET
4
3
2
1
HIGHLY CURVED PURSUIT COURSE DESCRIBED BY MISSILE
3
AXIS ALWAYS TOWARD TARGET
2
MISSILE AXIS & HOMING HEAD AXIS
1
MISSILE HOMING SYSTEM ACQUIRES TARGET AND MISSILE AXIS CONTINUOSLY COINCIDES HOMING HEAD AXIS TERMINAL GUIDANCE BEGINS

AQ.261

Figure 8-3.—Pursuit homing.

flight data unit, a vertical gyro unit, and a launching set.

Before the guided missile can be launched, the missile control system must supply the missile with certain data. The intercept radar set determines range and develops a proportional voltage which is supplied to the computer group and the CW radar group.

The CW radar group generates CW-RF energy which is injected into the waveguide assembly and transmitted by the intercept radar antenna.

The CW radar also develops a pseudo signal which is fed to the missile for the purpose of checking the operation of the missile's circuitry to the Doppler frequency region. When the target is within range, the pseudo signal is cut off. Now the CW radar group develops a simulated Doppler signal proportional to the closing range rate. This simulated Doppler signal is fed to the missile to tune the missile circuitry to the anticipated Doppler frequency region. It should also be noted that the CW radar supplies in-range information to the missile launching set.

In order to understand the operation of the various functions of the system after launching, the use of the CW radar is discussed first. Figure 8-5 illustrates a typical missile attack problem. As shown, the CW signal is transmitted by the intercept system's antenna and, when reflected by the target, is received by the missile's nose antenna.

The rear missile antenna receives the CW signal directly from the intercept radar antenna, and then both signals are compared in the missile's receiving system. Because the distance between the missile and the target is decreasing, the signal received from the target is changed in frequency with respect to the signal received directly from the intercept antenna. The difference between the two is the Doppler frequency which is directly proportional to the closing speed.

The Doppler signal is applied to the speed gate where it is compared to a reference signal. The speed gate prevents the missile from homing on some other object near the target but moving

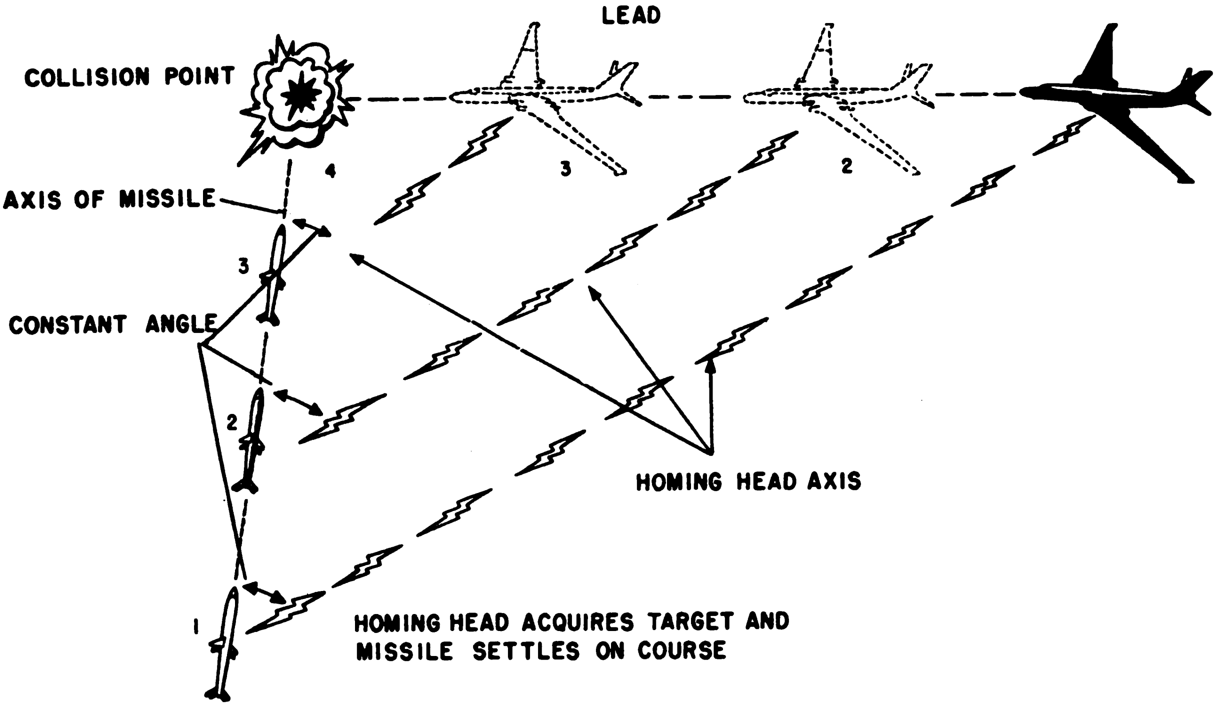


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Figure 8-4.–Lead homing.

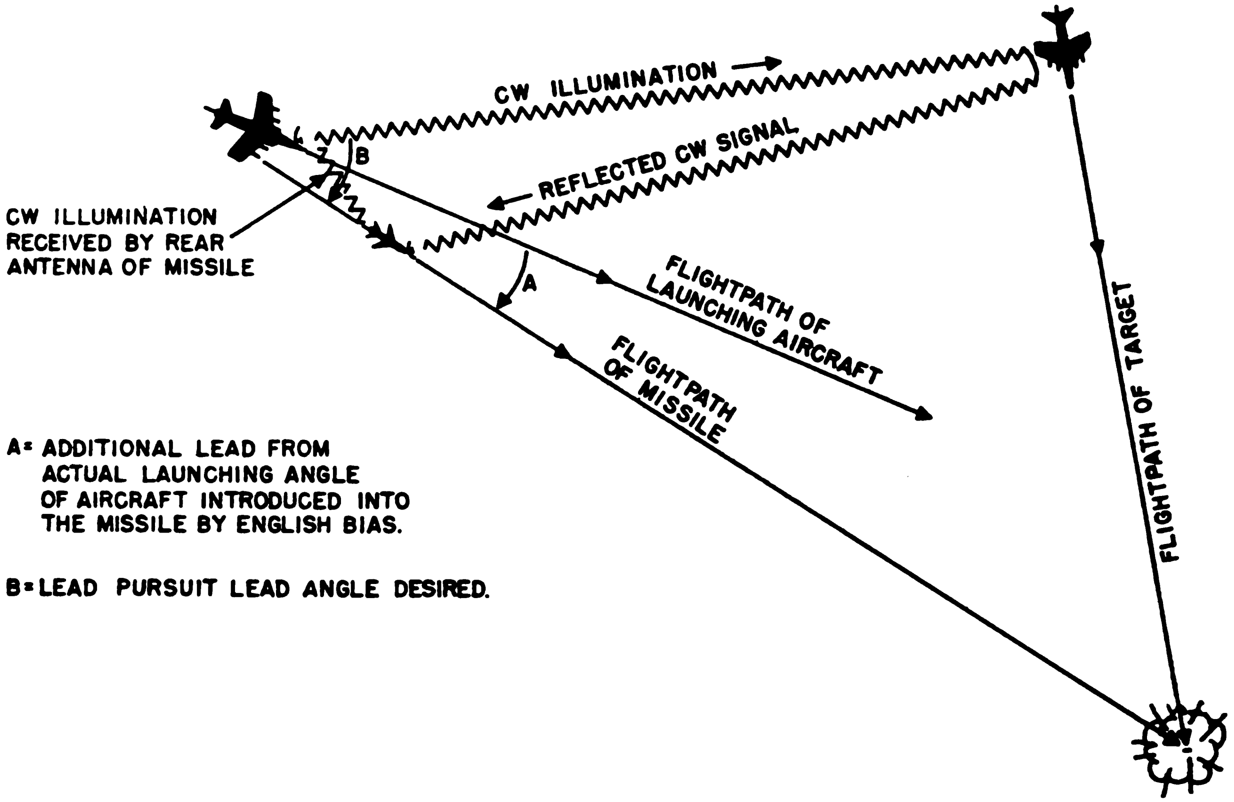
at a different velocity. Steering signals are provided within the missile by deriving error signals from the conical scan antenna when homing on the reflected CW energy from the target. The missile uses the constant look angle method of homing on a target. Coding and range modulation are used to prevent interference and to measure the range to the target.

The intercept radar is used to detect and track the aircraft targets. At the time of launch the intercept radar antenna position information is fed to the missile's nose antenna for the purpose of properly positioning it for target acquisition. Head-aim and English-bias information is provided to the missile that will insert any correction required in the event the launching aircraft is not on the exact lead pursuit course. After the intercept radar has locked on a target and the missile to be fired has been selected and armed, the pilot can fire the missile when the in-range signal comes on, provided his target is within the ASE (allowable steering error) circle.

As illustrated in figure 8-5, the lead pursuit course which the launching aircraft attempts to fly is shown by angle B. Because of limitations in aircraft performance or heading errors on the part of the pilot, the aircraft may not be able to fly an exact lead pursuit course. In this event a heading correction voltage (head-aim and English-bias) proportional to angle A is supplied to the missile prior to launching in order to bring it on course immediately after launching. The heading correction is a d-c voltage generated in the CW radar group and provided to the missile, but used by the missile only after it has been launched.

INTERCEPT SYSTEM

The purpose of the intercept system is to provide the pilot and the radar intercept officer (RIO) with the information required to locate and select the desired enemy target for auto-


CW ILLUMINATION
REFLECTED CW SIGNAL
B
CW ILLUMINATION RECEIVED BY REAR ANTENNA OF MISSILE
A
FLIGHTPATH OF LAUNCHING AIRCRAFT
FLIGHTPATH OF MISSILE
FLIGHTPATH OF TARGET
A= ADDITIONAL LEAD FROM ACTUAL LAUNCHING ANGLE OF AIRCRAFT INTRODUCED INTO THE MISSILE BY ENGLISH BIAS.
B=LEAD PURSUIT LEAD ANGLE DESIRED.

AQ.272
Figure 8-5.—Typical attack problem.

matic tracking. When a target is being tracked, the radar provides other portions of the missile control system with the target information necessary to direct the interceptor to launch the missile and to compute the required missile guidance signals. The radar presents the pilot of the radar intercept aircraft with steering and missile flying information required to fly the aircraft and to launch the missile to produce a kill. During search, the radar provides range, bearing, and elevation on all targets detected to the pilot and the radar intercept officer.

During the track mode of operation, the intercept radar provides range, bearing, and elevation of the target to the pilot and the radar intercept officer. It also furnishes the same data, together with the line-of-sight rate, to the CW radar computer, and displays aircraft steering error, attitude, and missile firing information. The radar antenna transmits the CW illumination energy for guidance of the Sparrow III missile.

The system also has provisions for a Sidewinder Extended Acquisition Mode (SEAM). The SEAM presentation consists of a circle and dot and is displayed when the AIM-9G missile head is locked on a target. The dot indicates the AIM-9G missile head position relative to boresight and the circle represents a 20° angular displacement reference.

PHASES OF OPERATIONS

In general, the operation of the system may be classified under four phases with each phase having one or more modes of operation. The phases of operation are standby, search, acquisition, and track. Each phase of operation is essential to the radar in accomplishing its purpose.

Standby

When it is desired to maintain radar silence the equipment is placed in standby, the condition for passive search operation. The AMCS is able to detect a jamming source, acquire it, and angle track it. All antenna search patterns are available at this time. Full data link capabilities also are available during this mode. Angle track and data link are discussed in detail later in this chapter.

Search

When the radar is in search condition, as signified by the presentation in figure 8-6, the radar intercept officer observes the indications on the radar to seek, identify, and select the target to engage, whether airborne or on the ground. Search operation is discussed in detail in the following paragraphs.

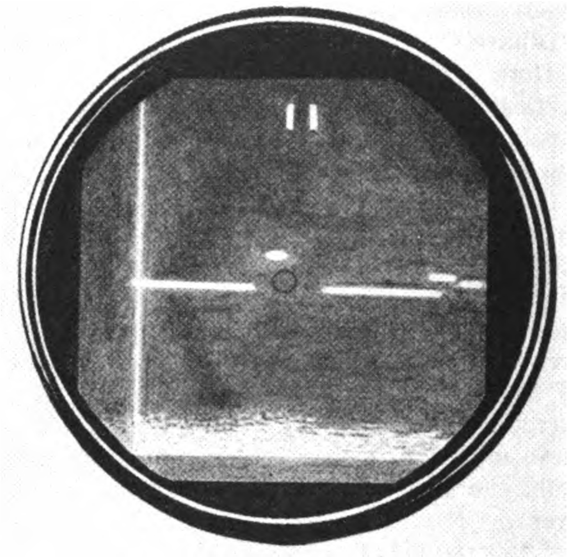


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Figure 8-6.–Radar presentation, search mode.

In the normal search condition, the radar is in full operation, and at this time the RIO can:

1. Arrange for the antenna to be driven in azimuth either automatically or manually. Automatic scan can be limited to 30° in azimuth (narrow scan) or it can cover the entire display width (wide scan).
2. Choose elevation antenna motion either on one level or three levels (one-bar or three-bar scan). The elevation at which either scan takes place is manually controlled by the radar intercept officer.
3. Select a display range of 10, 25, 50, 100 or 200 miles; or expanded sweep sectors of 10 or 16 miles.
4. Select one of two beam widths.
5. Select one of three types of polarization.
6. Select radar (air-to-air) or bomb mode (air-to-ground) operation.

The wide antenna scan is used when the aircraft is operating without ground control intercept (GCI) direction. While operating, the antenna scans back and forth in azimuth over an arc of 120° at the rate of 120° per second. The antenna hesitates at the end of each scan so that there will be no azimuth motion of the antenna if there is a change in elevation at this time, as in three-bar scan. The tilt of the antenna is adjusted by the RIO by means of the elevation control wheel on the radar control stick.

The narrow scan increases the detection capability of the system when the approximate position of the target relative to the aircraft is known. In this arrangement the antenna moves at one-half the speed (degrees per second) of wide scan, so that there are double the number of target returns per scan. The antenna moves through 30° of travel before returning to the original point. With only 30° scanned out of the 120° maximum travel available, it is possible to choose an area of search anywhere within the display area.

The three-bar scan is provided to increase the search area when the elevation of the target is not known. The RIO selects three-bar operation and at the end of each azimuth scan, the antenna jumps 3.75° in elevation. As a result, the overall elevation coverage, including antenna beam width and the effect of spinning the feedhorn (nutation), is 12.2°. The three-bar scan pattern is the same in narrow or wide scan. The vertical center of the three-bar pattern can be positioned in elevation within ±50° by means of the elevation control wheel.

The one-bar scan is useful during search when the exact elevation is known, or on flights at low altitude during which a deeper scan could result in pickup of clutter from the ground. In this pattern the number of scans over a particular area per unit time is increased so that tne chance of detecting a target at that elevation is also increased. Moreover, with the elimination of the elevation jump characteristic of the three-bar scan, the same information is painted over and over on the indicators, thereby improving the viewer's chance of seeing the target.

The polarization of the energy being transmitted can be controlled by the RIO for optimum system performance. In the radar mode the RIO chooses either linear polarization or one of two available circular polarizations, depending on the weather. In clear weather, linear polarization is normally used because it provides the greatest detection capability; but in the presence of clouds circular polarization may be an advantage because of the increased possibility of seeing through the cloud (fig. 8-7). The RIO can choose circular polarization in either direction by setting the POLAR switch on the radar set control at CIR 1 or CIR 2. During an air intercept, only LIN or CIR 1 can be used because they are compatible with the antenna on the Sparrow III missile.

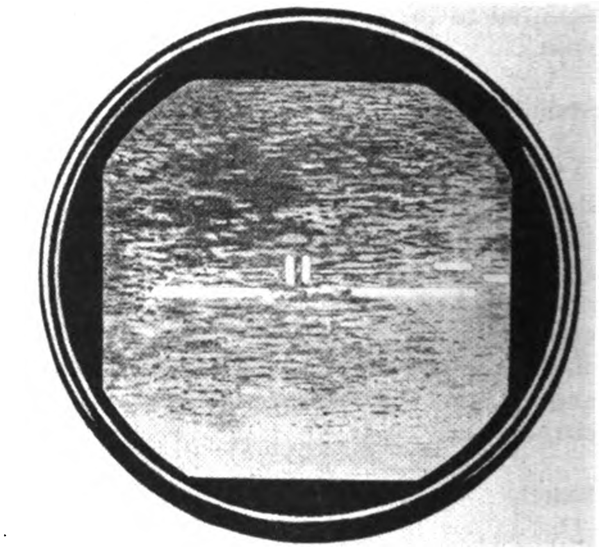

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Figure 8-7.—Radar presentation, showing weather.

During search the RIO has the choice of one of two receivers. His selection usually depends upon the type of clutter encountered and the range under search. One of the receivers has the capability of seeing through clutter, but with reduced detection capability (fig.8-8).

A specialized method of search is available to the RIO for use at search display ranges of 100 to 200 miles. If the azimuth and elevation of the target are known to the RIO, he can achieve maximum detection capability of the radar set by stopping automatic search and manually positioning the antenna in the direction of the target. He then can arrive at spot light operation by pressing the lockon switch on the radar control stick to full-action position and manually positioning the antenna with the radar control stick. Nutation of the antenna feedhorn is stopped at this time to reduce antenna beam width to a minimum, so that the maximum amount of RF energy is concentrated in the smallest area. Conversely, for additional azimuth and elevation coverage, the lockon switch is returned to half-action position, restoring nutation.

Acquisition

Acquisition is the process of selecting and locking on a target. If it is successful, the radar is switched from search to the track condition. Various phases of acquisition are discussed in the following paragraphs.

In the normal acquisition process the RIO moves the radar control stick so that an acquisition symbol displayed on the indicator brackets

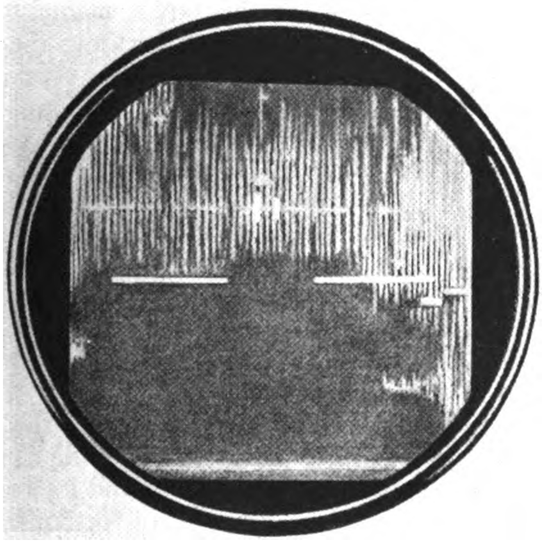

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Figure 8-8.—Radar presentation showing clutter.

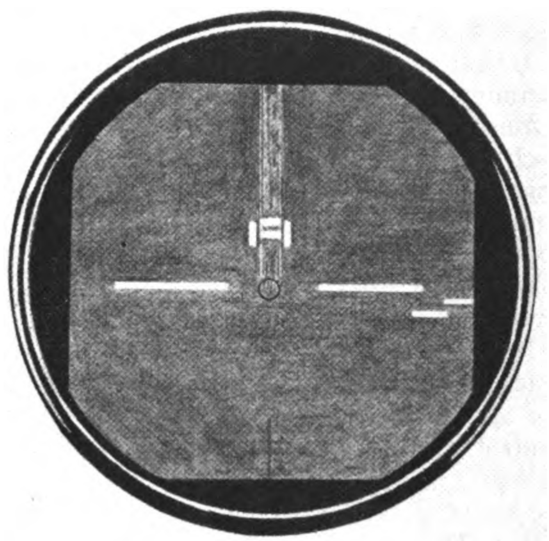

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Figure 8-9.—Radar presentation, acquisition mode.

the selected target. He then presses the lockon switch to half-action position, causing the antenna to stop scanning and slew to the azimuth position of the acquisition symbol (fig. 8-9). At this time a range strobe appears on the presentation as an intensified spot on the B-sweep, centered between the bars of the acquisition symbol. The radar control stick is then positioned to place the range strobe directly over the target dot. By moving the acquisition symbol and the range strobe to the target position, the RIO adjusts the radar circuits for acquisition. Now when the lockon switch is pressed to the full-action position, the radar automatically proceeds to acquire the target and start tracking.

If before acquisition, the radar had been searching in the three-bar scan pattern, the target return could have appeared on any of the three bars. Since the antenna is positioned on the center bar during acquisition, a target return on the center bar could in some situations be lost beyond the edge of the radar beam. To prevent such loss of targets, the antenna is made to nod 2° above and below the center bar elevation, in effect broadening the beam to include off-center returns.

Acquisition can be achieved only in the air intercept (AI) display ranges of the radar. If it is attempted in 100- or 200-mile display range, the system switches to the spotlight condition of search. The RIO can then maintain surveillance of the target until the range is suitable for acquisition. At that time he sets the RANGE switch for the desired AI range and normally acquires the target. It is also possible to have target presentation after lockon if expanded sweep is used during search and acquisition. After lockon, the system automatically returns to normal display range presentation. If the expanded sweep is delayed to present a range more distant than the setting of the RANGE switch but not exceeding the maximum AI range of 50 miles, and a target is acquired at that range, the target will not be within the display range after lockon. Therefore it will not be displayed, but lack of a displayed target will not interfere with lockon and normal tracking. Increasing the display range will return the target to the display.

If during search, a source of noise or CW jamming of sufficient strength to prevent normal acquisition is encountered, the jamming source itself can be used as the target, but only for angle tracking (fig. 8-10). Acquisition of the jamming source is less desirable than normal acquisition, because range information normally available by radar cannot be obtained from the direct transmission out of the jamming source.

In acquiring the jamming source, the RIO brackets the azimuth position of the source with the acquisition symbol by means of the radar control stick, and then presses the lockon switch to half action. If the target is still obscured by the jamming, he presses the lockon switch to full action. The system then automatically acquires the jamming source and starts angle track.

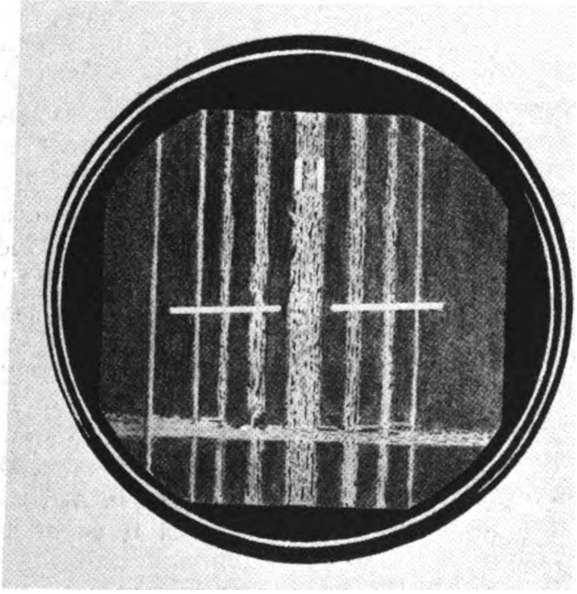

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Figure 8-10.—Radar presentation, acquisition on jam.

Under certain conditions, as for example when a target is visible during jamming but the jamming is preventing normal acquisition, it may be desirable to track the target manually. To acquire a target for manual tracking, the RIO sets the TRACK switch on the radar set control at MAN, brackets the target with the acquisition symbol, and presses the lockon switch on the radar control stick to half action. The antenna sweeps to the azimuth position of the acquisition symbol and the range strobe appears on the B-sweep. With the radar control stick, the RIO positions the range strobe just in-range from the target (closing target) and presses the lockon switch to full action. The radar now switches to an aided manual track condition.

Another acquisition mode is labeled the Pilot Lockon Mode (PLM). PLM provides the capability of pilot initiated acquisition and lockon. In this mode, the pilot has priority for control of the radar. When the pilot's target acquisition enable switch (TAE) is pressed to half action, the antenna is commanded to a boresight position, and a 5-mile range B-sweep is selected for display. Flying a pursuit course, he presses the TAE switch to full action. After a time delay, the full action command is passed to the synchronizer in preparation for lockon. Also after the time delay, a range sweep strobe is initiated which can be programmed by the pilot to either sweep from 5 miles to 0.5 mile, or from 0.5 mile to 5 miles (sweep IN or OUT). The target detector circuits in the synchronizer then compare the target return with the sweeping strobe signal. When coincidence occurs in time, the radar locks on the target automatically and angle track is initiated.

Track

Upon successful completion of acquisition, the radar set is in track condition. The radar now sends target information to the computer in the CW radar system, which computes the intercept course to be flown. Target, aircraft steering, and missile launch information are presented to both the RIO and the pilot. During the course of the intercept, at the discretion of the pilot, the missile is launched at the target. Various phases of tracking are discussed in following paragraphs.

The normal track condition, which begins after the successful completion of a normal acquisition, is the most favorable condition for intercepting a target. At this time the radar set is automatically tracking the target in angle and range (fig. 8-11). The information obtained during this process, along with aircraft steering and missile launch information, is displayed to both the pilot and the RIO. Since the information fed to the CW radar system computer is the most accurate and complete, as compared with the information during other tracking phases, the aircraft steering and missile launch information is most accurate, and consequently the possibility of a kill is greater.

If the target fades for a short time, the radar set maintains the track condition by continuing to track the position the target would reach, assuming that the range rate and angle rate remain constant. When the target reappears the radar resumes normal track. All track information is displayed, even during the fade time, so that there is no interruption in the attack. If the target fails to reappear within 5 seconds, the radar automatically returns to search operation.

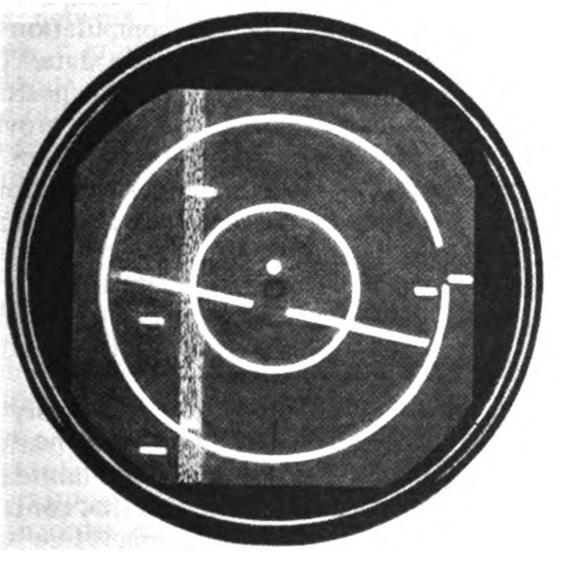
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Figure 8-11.—Radar presentation, normal track mode.

If, during normal track, a target starts jamming in such a manner as to prevent the radar from continuing normal track, the system automatically switches to a home-on-jam (HOJ) condition. At this time, angle track is maintained on the jamming source in place of the target, and range track is maintained by operating on memorized range and range rate. Otherwise the intercept can continue in the normal manner for a successful kill. If, at any time, the target return reappears on the indicator, the radar can automatically reacquire it to resume normal tracking. If this automatic action fails, the RIO can try to reacquire the target by pressing the lockon switch to half action, setting the range strobe over the target with the radar control stick, and then pressing the lockon switch to full action. If the radar successfully reacquires the target, normal tracking is resumed. If the reacquisition is not successful, the system switches to acquisition-on-jam (AOJ) operation.

When the system switches to the AOJ tracking condition from HOJ, only angle information is available to the radar set and therefore only angle information is displayed. The pilot can guide the aircraft into position for a successful attack with the steering information provided; but display of the ideal range for launch is not available, and consequently, the pilot must decide the range at launch. If at any time during AOJ operation the target appears on the indicator, the RIO can try to acquire the target by pressing the lockon switch to half action, positioning the range strobe over the target, and pressing the lockon switch to full action. If the radar successfully acquires the target, normal tracking results. If the target still cannot be acquired, AOJ tracking resumes. At this time the RIO can decide whether to remain in AOJ, try to acquire again, or try manual track of the target.

The Manual track capability enables the RIO to track the target manually when automatic track is not possible. Angle and range information is generated by the radar and displayed to the pilot and RIO. The accuracy of the information is not as great as in normal track, but a successful attack and kill can be made.

After acquisition for manual track has been completed, the RIO checks the ANGLE LOCK light on the radar set control. If the light is on, indicating that the antenna servosystem is in automatic track, the RIO presses MAN Vc control to put the antenna under manual control as indicated by the ANGLE LOCK light going out. (Since the range strobe is not in coincidence with the target, angle track information is not gated into the antenna servosystem; consequently the antenna would drift off the target if automatic angle track were maintained.) The RIO then adjusts the MAN Vc control to keep the range strobe at a constant distance from the target rather than directly over the target on the display, because the strobe would obscure the target and make manual angle track more difficult. He then must decide how to operate in manual track. He has the following alternatives:

1. Continue as above, with aided range track and full manual angle track. This method is usually preferred in the absence of jamming.
2. Operate with automatic angle track, achieved by pressing the MAN Vc control (ANGLE LOCK lamp lit). If there is any jamming, the system will angle track it. If there is no jamming the RIO must first place the range strobe directly over the target in order to gate angle error information into the antenna servo circuits. If the range strobe is allowed to drift away from the target, the antenna servosystem will not receive any error information and the antenna might drift.

Polarization is effective in track as well as search. If weather or jamming interferes during any part of the track operation, the RIO can change the polarization of the transmitted energy to either linear or circular. The circularly polarized energy can be made to rotate in either direction.

If at any time during track, the RIO wishes to reject the target and return to search, he presses the lockon switch to half action and releases it. The radar automatically returns to the search pattern it was following when the track condition was intiated. The RIO can select another target at the same azimuth and elevation (visible in the B-sweep during track) without losing angle track. To do this, he presses the lockon switch to half action, positions the range strobe over the new target, and then presses the lockon switch to full action. The radar then automatically acquires the new target.

THEORY OF OPERATION

The radar is composed of a number of functional subsystems. The transmitting system produces the pulsed RF energy which is radiated by the antenna to illuminate any targets in the area covered by the antenna pattern. The return from the targets is received by the antenna and sent to the receiving system by the duplexer. The receiver amplifies and detects the low power RF return energy and applies the resulting video signal to the display system for target observation and to the range and angle tracking systems during track operation. To maintain a constant target signal in the range and angle track systems, the receiver gain is controlled by the automatic gain control system. The display system provides the pilot and radar intercept officer with the information required to operate the radar and to fly the aircraft to achieve a successful interception. The information presented is derived from many sources. The range track system automatically determines the target range and range rate for use in the computer of the CW radar system in the computation of attack course and missile guidance data. The angle track system controls the antenna position to maintain target illumination and provide target bearing and line-of-sight rate, also required by the CW radar system. A program is developed for driving the angle search system in the antenna through the required search pattern. To stabilize the search pattern during aircraft maneuvers and to provide aircraft attitude information to the display system, the vertical reference system is required.

The following discussion of the theory of operation is arranged according to the various subsystems described above and is not limited to the particular black box or chassis that contains the major portion of that subsystem.

Transmitting System

The purpose of the transmitting system is to generate the RF energy which is radiated by the antenna to illuminate the area under search. The transmitter produces a high power RF pulse, the frequency of which can be preset to any value between the limits of 8,700 and 9,400 MHz. The pulse width can be either 2 or 0.4 microseconds. The width actually used is a function of the operating mode of the radar as determined manually by the operator, or automatically during the tracking operation.

The pulse repetition frequency (PRF) is dependent upon the range selected and the width of the particular RF pulse that is being transmitted.

A synchronizing pulse, coincident in time with the RF transmitted pulse, is also supplied by the transmitting system. The synchronizing pulse is used as a zero time reference for all other circuits in the radar. During standby operation, with the transmitter not operating, a standby trigger is provided to permit operation of other portions of the radar in the passive modes and during ground testing.

Figure 8-12 is a block diagram of the transmitting system. When keyed with a high-voltage pulse from the modulator, the magnetron oscillates at the frequency determined by its cavity. In generating the required high voltage pulse, the high voltage power supply resonantly charges a pulse forming network to approximately twice the steady d-c voltage. The energy is stored in the network. When discharge thyratron V402 fires, it grounds one end of the pulse forming network, and the stored energy flows through the other end of the network to the primary of pulse transformer T401. The output of the transformer, stepped up 4:1, is applied to the magnetron.

The PRF generator determines the PRF at which the transmitter fires, but its output pulse does not have sufficient energy to fire the discharge thyratron directly. For this reason the pulse is applied to trigger blocking oscillator V404, the output of which fires trigger thyratron V403. The resulting high-current pulse from V403 insures positive firing of discharge thyratron V402.

In order to maintain constant power out of the transmitter, it is necessary to regulate the peak anode current in the magnetron. In this system, current regulation is achieved by changing the voltage applied to the pulse forming network so as to control the amplitude of the input pulse to the magnetron. To this end the peak anode current regulator adjusts the output of the high voltage power supply. Any increase in amplitude of the magnetron current causes a proportionate change in the output of pulse peak detector V407, which acts on anode current regulator Z403 to reduce the 3-phase, 400-Hz input to the high voltage power supply.

The RF pulse width is determined by the pulse forming network, which is actually a high-power delay line (fig. 8-12). When the network is discharged, a pulse travels down the line and returns, equal in magnitude but opposite in polarity, thereby discharging the line. The time required for this discharge is the output pulse width and is determined by the electrical length of the line. If there is an impedance between the network and the pulse transformer, when the pulse forming network is discharged, the return pulse on the network may be more negative than the initial pulse. The result is a residual negative charge on the network. On the next resonant charging cycle, the network would then charge to a high potential than desired, and each succeeding cycle would in turn produce an even larger negative residual charge, the process continuing until some component in the loop is destroyed. To prevent such a contingency, an inverse diode is provided, which grounds out residual negative voltage on the network.

The temperature of the magnetron cathode must be held constant. When the system is turned on after a considerable off period, the required heating is supplied by the filament, but as the magnetron continues to operate, the cathode current also furnishes heat. Since the current magnitude is somewhat fixed by the requirements of the system, a constant cathode temperature can be achieved only by reducing the heat contributed by the filament. When the system is in an operating mode, all filament voltage is removed from the magnetron, because the average magnetron current alone is sufficient to provide full cathode heating.

The waveguide system performs a number of functions in addition to the transmission and reception of RF energy. These functions are described in the following paragraphs.

The ferrite isolator (fig. 8-12) connected between the magnetron and the antenna absorbs reflected RF energy during transmission, while permitting the transmitted energy to pass with very little restriction. This reflected energy

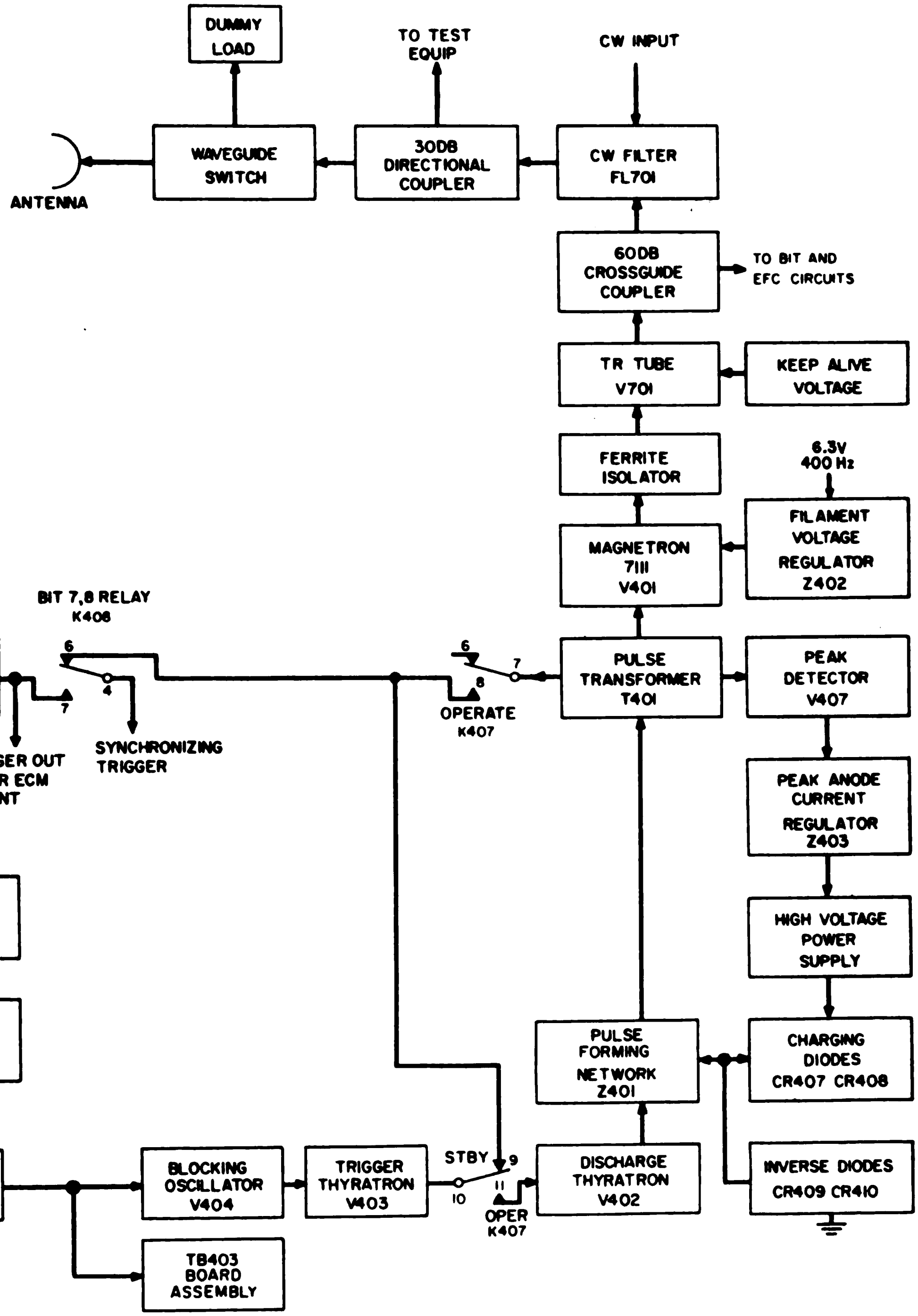

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Figure 8-12.—Transmitting system, block diagram.

could distort the transmitted pulse and change the magnetron frequency.

The dual TR tube and its two adjoining hybrid junctions act as a switch to protect the receiver from transmitted energy. The TR tube is always maintained slightly below breakdown potential to provide for rapid ionization when the transmitted pulse appears. The resulting short circuit in the waveguide inserts attenuation in the path of the transmitted energy at the entry to the receiving system.

During transmission, filter FL701 couples the CW energy from the CW radar system to the antenna and prevents its entry into the receiving or transmitting circuits of the intercept radar. The filter presents a low insertion loss to the transmitted and received signals of the intercept radar.

The waveguide switch is provided to direct the transmitted energy into a dummy load during built-in tests. In normal operation, the dummy load is bypassed and the RF energy is passed to the antenna.

The RF energy is coupled through two rotary joints on the antenna gimbals before being fed to the feedhorn. These joints allow free movement of the antenna in azimuth and elevation to 120° without interfering with the transmission of the RF energy.

The RF energy from the feedhorn is concentrated and directed by the parabolic reflector of the antenna. The feedhorn is offset from the center axis of the reflector and is rotated by a spin motor so that the beam axis describes a conical path and the RF energy is lobed in a pencil-shaped beam about the center axis of the reflector. When the radar set is not in operation, a shutter protects the receiver crystals from high power transmissions from other radars nearby. When the system is operating, the shutter is held open and passes RF signals to the receiver. When the system is turned off, the shutter closes automatically and attenuates all signals approximately 30 db.

The antenna provides the means for radiating both pulsed and continuous wave signals and for receiving target echoes. It is mechanized so it can be either manually directed in azimuth and elevation or provide several types of automatic scanning motion. It also is capable of changing the polarization of the transmitted energy.

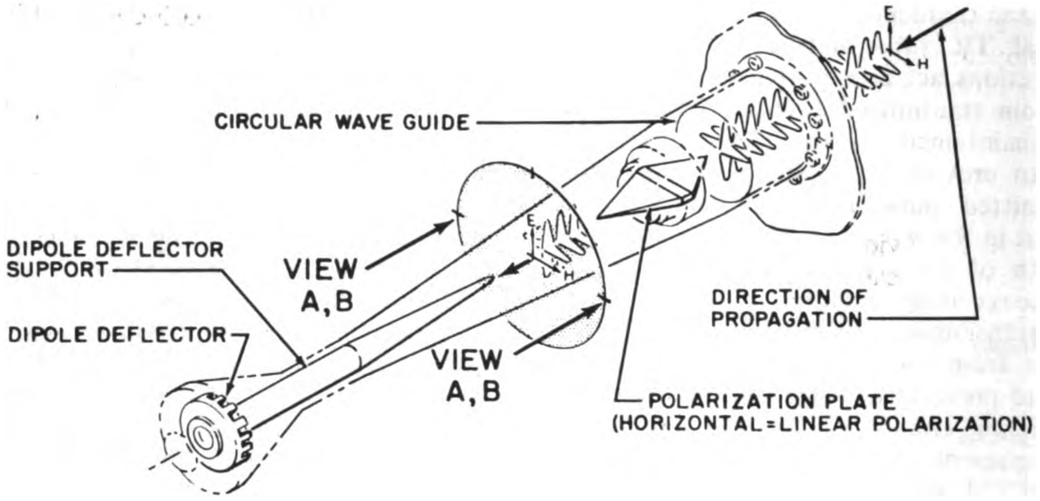
Normally the energy transmitted to the antenna through the circular waveguide feedhorn is linearly polarized. Polarization refers to the orientation of the plane of electromagnetic oscillations as the wave progresses through the waveguide and through free space. During clear weather and in the absence of jamming signals, the linearly polarized transmitted energy produces effective target echoes, but in rain or fog both the transmitted pulses and the target echoes undergo attenuation. Similarly, linearly polarized clutter produce, by electromagnetic interference, the same effect as attenuation of transmitted and received energy from atmospheric causes. Whatever form the interference or clutter takes, it obscures the target returns.

Considerable improvement in radar performance can be realized by resorting to circular polarization of the transmitter output. Circular polarization is achieved by means of a polystyrene quarter-wave plate inserted in the feedhorn circular waveguide (fig. 8-13).

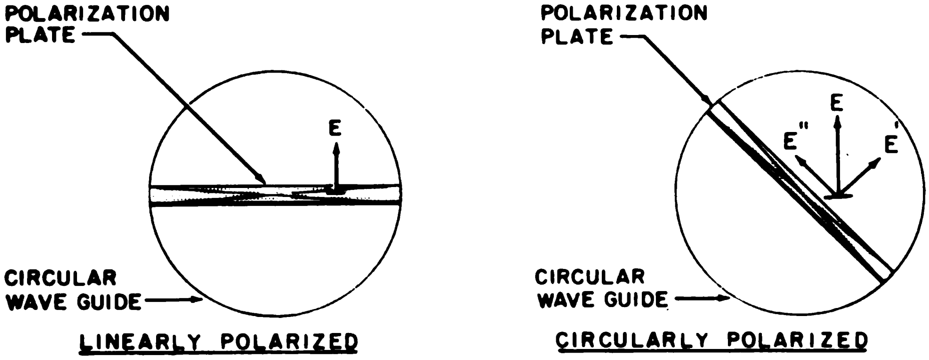
The speed of propagation of an electromagnetic wave is slower in higher dielectric materials than in air. Therefore, any portion of the transmitted wave which passes through the quarter-wave plate is slowed down. For the mode of polarization in use, the vertical E-field is concentrated at the center of the circular waveguide. Thus, when the plate is horizontal, as shown in view A of figure 8-13, practically all of the energy passes perpendicularly through the plate and continues into space without change in polarization.

For circular polarization, the quarter-wave plate is rotated 45° either side of vertical. The vertical E-field intersects the plate at 45° and can be considered as resolved into two component fields; one in the plane of the plate and the other perpendicular to it. The component of the field in the plane of the plate passes through the quarter-wave length of the plate and is delayed by 90°. The perpendicular component of the field traverses only the relatively thin cross section of the plate, so that it is only slightly delayed. The result is that the two components of the field are 90° apart, and the recombined E-field rotates at a speed equal to the transmitted RF energy.

Circularly polarized target echoes are reformed by the plate into linearly polarized waves. Because its mount has a separate bearing, the quarter-wave plate is free to rotate independ-



FEEDHORN



LINEARLY POLARIZED

VIEW A

CIRCULARLY POLARIZED

VIEW B

AQ.270

Figure 8-13.—Circular and linear polarization.

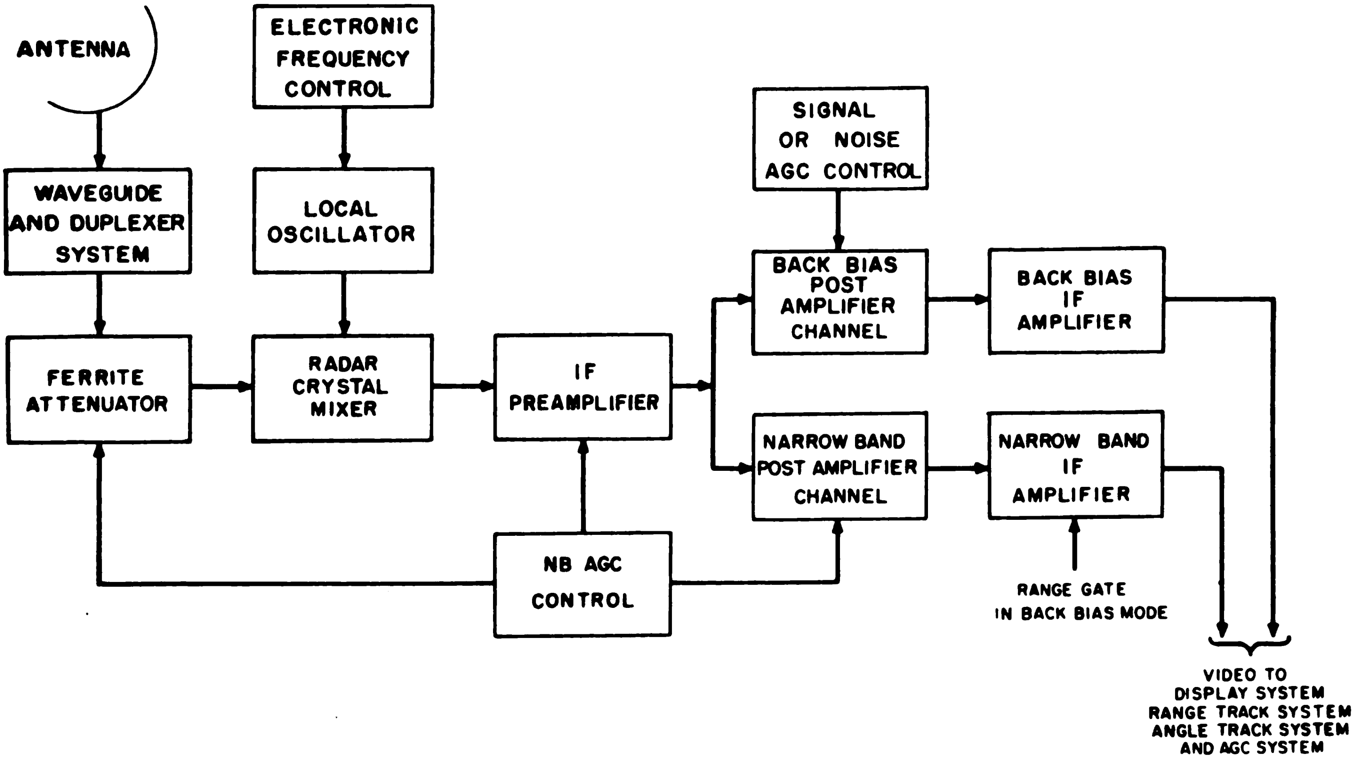
ently on the feedhorn assembly, or it can remain fixed while the feedhorn is rotating. Control of the plate position is accomplished by the magnetic stop assembly, a cast ring clamped on the circular waveguide section. Two solenoids on the ring operate pawls that project through the waveguide wall. As the feedhorn rotates, bearing friction causes the plate assembly to rotate until it touches one of the pawls. It is held in that position by the rotational force of the feedhorn.

Receiving System

The purpose of the receiving system is to receive the weak target signal return and to amplify the signal to a suitable level for use in the angle tracking, range tracking, and display circuits. The target return frequently is obscured by various forms of clutter, from natural sources such as ground or cloud return or from unfriendly interference caused by jamming. To provide target discrimination against certain of these clutter signals, a special back bias receiving channel is employed. However, back bias operation is not compatible with the high degree of receiver sensitivity required for maximum detection capability. For this reason, a second receiving channel is provided which does have maximum sensitivity. To achieve this characteristic a very narrow bandwidth is employed, and therefore this channel is called the narrow band channel. Selection of the particular channel can normally be made by the operator with the CLUTTER switch. An exception is, if tracking was initiated in the narrow band channel and the target amplitude is sufficient, an automatic transfer is made to the back bias channel.

When a target is being tracked in the back bias mode (heavy clutter), IF gating is employed in the narrow band receiver which is used to provide the angle track information. This is covered in further detail under angle track operation.

Echoes received by the antenna are passed through the waveguide and duplexer system and mixed with the output of the local oscillator to produce a 30 MHz intermediate frequency (fig. 8-14). The 30 MHz signal is detected by the mixer crystals and applied to the preamplifier, where it is amplified and sent to the post amplifier. When the signal enters the postamplifier, it is split into two separate channels, one supplying the narrow band IF amplifier and the


ANTENNA
ELECTRONIC FREQUENCY CONTROL
SIGNAL OR NOISE AGC CONTROL
WAVEGUIDE AND DUPLEXER SYSTEM
LOCAL OSCILLATOR
BACK BIAS POST AMPLIFIER CHANNEL
BACK BIAS IF AMPLIFIER
FERRITE ATTENUATOR
RADAR CRYSTAL MIXER
IF PREAMPLIFIER
NARROW BAND POST AMPLIFIER CHANNEL
NARROW BAND IF AMPLIFIER
NB AGC CONTROL
RANGE GATE IN BACK BIAS MODE
VIDEO TO DISPLAY SYSTEM RANGE TRACK SYSTEM ANGLE TRACK SYSTEM AND AGC SYSTEM

AQ.271

Figure 8-14.—Receiving system, block diagram.

other, the back bias IF amplifier. The signals that enter the narrow band channel of the IF postamplifier are coupled to the narrow band IF amplifier, where they are amplified and limited before application to the narrow band filter. The signals are then detected, and finally are coupled to video amplifiers for use in the display, range tracking, and angle tracking circuits. Likewise, the signals that enter the back bias channel of the IF postamplifier are coupled to the back bias IF amplifier, where they are amplified and detected. The resulting output is coupled to the video amplifiers for use in the display and range tracking circuits during heavy clutter conditions or when the target returns exceed a preset threshold level.

The local oscillator is a reflex klystron which generates a signal 30 MHz above the radar transmitted frequency. The signal is mixed with the target return signal to produce the 30 MHz IF signal at the radar crystal mixers and the electronic frequency control (EFC) crystals. The 30 MHz frequency difference is maintained by the EFC circuit, which adjusts the local oscillator output frequency by changing the amplitude of the d-c voltage applied to the reflector of the klystron. Manual tuning is also possible by mechanical adjustment of the klystron cavity.

The IF preamplifier receives and amplifies the 30 MHz output of the crystal mixers and supplies the signal to the two channels of the postamplifier for further amplification. Provision is made for varying the gain of the receiver during track operation by applying AGC voltage to the grids of the first and third stages of the two post amplifier channels. The narrow band IF amplifier, which receives the output of the narrow band channel of the postamplifier, consists of two wide band amplifier stages, a limiter, a range gated stage, two narrow band amplifier stages, a narrow band filter network, a diode detector, and a video cathode follower.

During back bias track operation a gate timed to correspond to target range is received from the range tracking circuits of the synchronizer. Only the signals occurring during the time of the gate are coupled through the following stages.

The back bias IF amplifier, which receives the output of the back bias channel of the postamplifier, consists of eight stages of IF amplification, a diode detector, and a video cathode follower. The back bias IF amplifier provides a receiver channel of wide bandwidth and large signal handling capacity in order to improve target detection in the presence of clutter and jamming.

The back bias amplifier stage incorporates values of cathode resistance which are higher than normally encountered in conventional IF amplifiers. The stages also incorporate cathode bypass capacitors. The cathode capacitance, in conjunction with the tube characteristics, determines the delay time for immediate automatic gain control (IAGC); i.e., self-acting automatic gain control within each stage. The IAGC operates in each stage of the amplifier in a manner which allows the amplitude of a desired signal to be constant whether or not an undesired signal is present. The output produced by a desired signal is the result of the step change in the envelope of the undesirable IF voltage when the desired signal appears. Figure 8-15 illustrates this action. The operating point of a back bias amplifier stage is shown on the curve in part (A) of the figure. When clutter is applied to the tube, IAGC action reduces the clutter signal sharply by moving the bias point with a time constant determined by the value of the cathode capacitor and the tube characteristics.

The gain of a desired signal appearing in the presence of clutter will remain constant, because of this back biasing characteristic of the amplifier. Since the clutter signal and the target return cannot be phase-coherent, but differ by the Doppler frequency, the idealized output signal from the stage appears as shown in figure 8-15(B). The desired signal is shown after the voltage spike as a narrow fluctuating signal. The envelope of the signal from the back bias IF amplifier stages which fluctuates at the Doppler frequency, is shown in (C) of figure 8-15.

The EFC performs two functions: (1) it establishes the intermediate frequency (IF) of the system at the center frequency (30 MHz) of the receiver immediately after the transmitter is turned on, and, (2) it maintains the intermediate signal frequency within the pass band of the receiver. These functions are accomplished by controlling the output frequency of the local oscillator as was mentioned earlier in this chapter.

The EFC circuits are shown functionally in figure 8-16. A sample of the transmitted pulse is

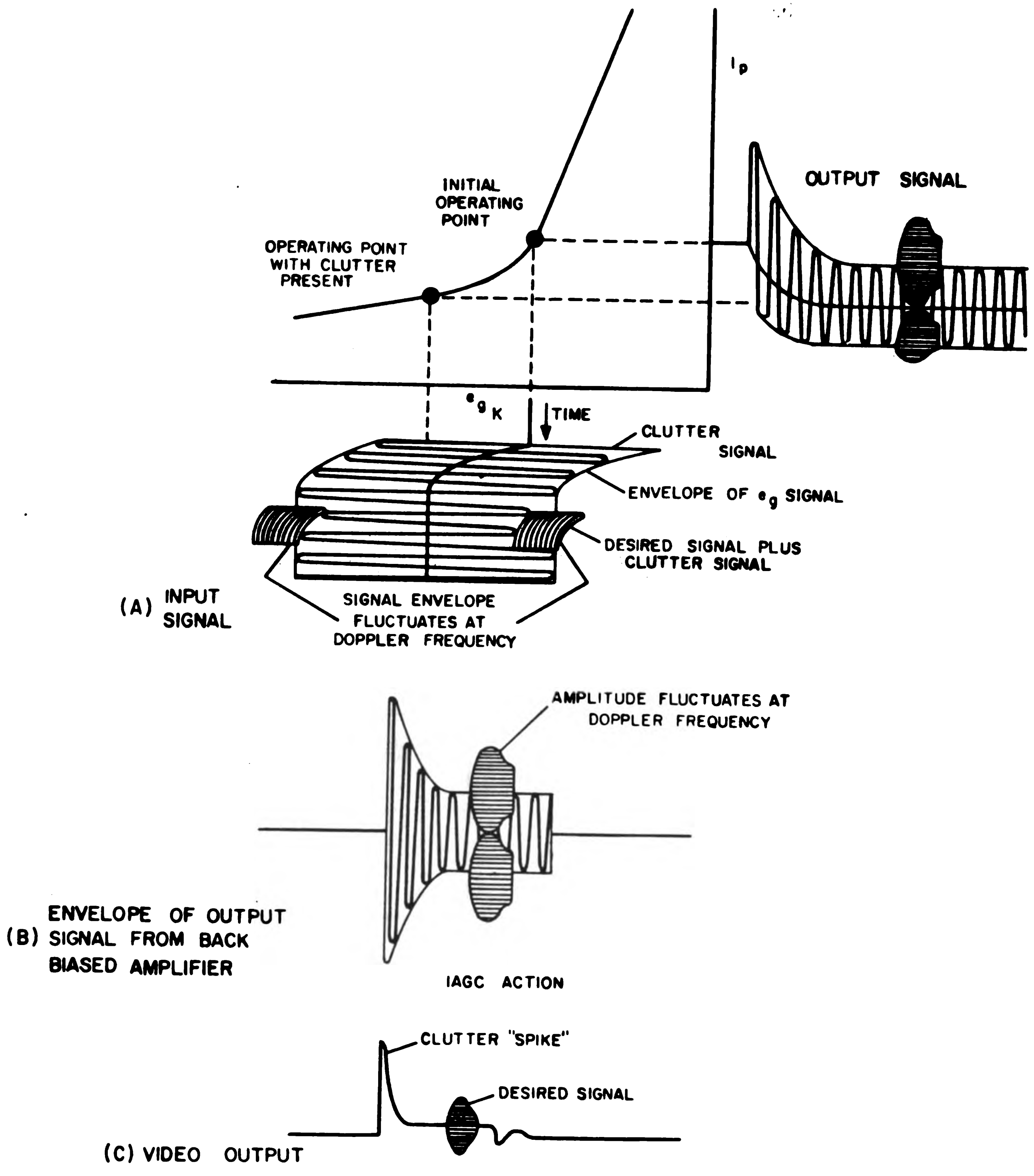

Ip
INITIAL OPERATING POINT
OPERATING POINT WITH CLUTTER PRESENT
OUTPUT SIGNAL
eg K
TIME
CLUTTER SIGNAL
ENVELOPE OF eg SIGNAL
DESIRED SIGNAL PLUS CLUTTER SIGNAL
(A) INPUT SIGNAL
SIGNAL ENVELOPE FLUCTUATES AT DOPPLER FREQUENCY
AMPLITUDE FLUCTUATES AT DOPPLER FREQUENCY
(B) ENVELOPE OF OUTPUT SIGNAL FROM BACK BIASED AMPLIFIER
IAGC ACTION
CLUTTER "SPIKE"
DESIRED SIGNAL
(C) VIDEO OUTPUT

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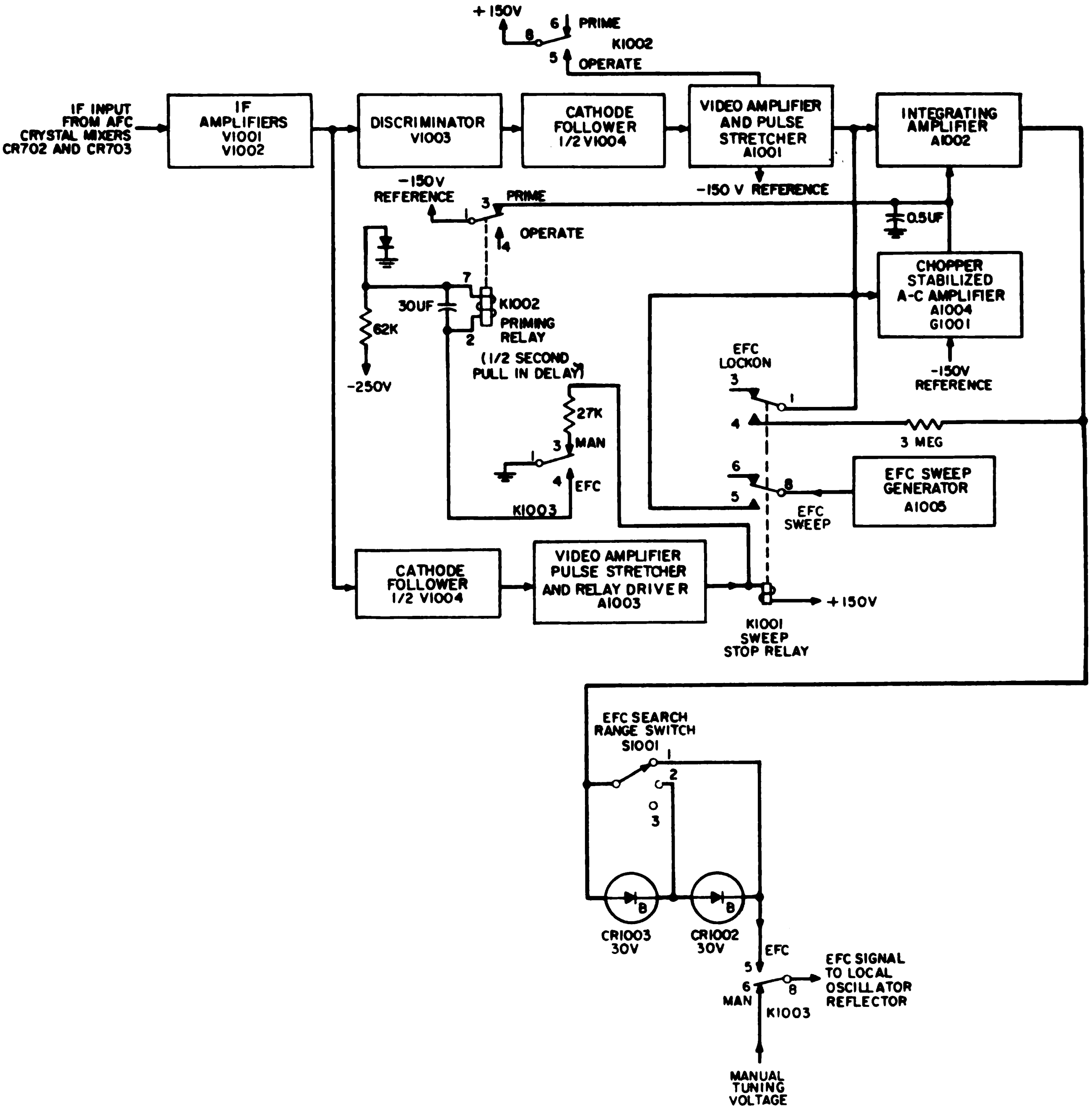
Figure 8-15.—Signals in back bias amplifier.


+150V
6
8
PRIME
K1002
5
OPERATE
IF INPUT FROM AFC CRYSTAL MIXERS CR702 AND CR703
IF AMPLIFIERS V1001 V1002
DISCRIMINATOR V1003
CATHODE FOLLOWER 1/2 V1004
VIDEO AMPLIFIER AND PULSE STRETCHER A1001
INTEGRATING AMPLIFIER A1002
-150V REFERENCE
1
3
PRIME
4
OPERATE
-150 V REFERENCE
0.5UF
7
30UF
62K
K1002 PRIMING RELAY
2
(1/2 SECOND PULL IN DELAY)
-250V
CHOPPER STABILIZED A-C AMPLIFIER A1004 G1001
-150V REFERENCE
EFC LOCKON
3
1
4
3 MEG
27K
3
MAN
1
4
EFC
K1003
6
8
5
EFC SWEEP
EFC SWEEP GENERATOR A1005
CATHODE FOLLOWER 1/2 V1004
VIDEO AMPLIFIER PULSE STRETCHER AND RELAY DRIVER A1003
+150V
K1001 SWEEP STOP RELAY
EFC SEARCH RANGE SWITCH S1001
1
2
3
B
B
CR1003 30V
CR1002 30V
EFC
5
6
8
MAN
K1003
EFC SIGNAL TO LOCAL OSCILLATOR REFLECTOR
MANUAL TUNING VOLTAGE

AQ.274

Figure 8-16.—Electronic frequency control circuits, simplified block diagram.

coupled to EFC crystals CR702 and CR703. The local oscillator output, 30 MHz above the transmitted frequency, is mixed with the sample of the transmitted pulse. The difference frequency signal resulting from the mixing is applied to IF amplifiers V1001 and V1002, where it is amplified to a usable level and applied to frequency discriminator V1003.

The discriminator circuit develops negative pulses when the frequency difference is above 30 MHz and positive pulses when the frequency difference is below 30 MHz. These are coupled to the video amplifier and pulse stretcher through cathode follower V1004B.

The pulse stretcher widens a pulse to approximately 300 microseconds long with an amplitude proportional to the frequency deviation from 30 MHz. When the difference frequency is above 30 MHz, the stretched pulse is negative, and when the difference frequency is below 30 MHz, the pulse is positive. These pulses are coupled to the integrating amplifier (A1002), depending upon the negative–or positive–going pulses from the pulse stretcher. The output of the integrating amplifier is a negative voltage which is applied to the reflector of the local oscillator klystron to control the frequency of its RF output. This function closes the EFC loop.

Integrating amplifier A1002 develops a positive-going voltage for a negative-going input. An example of a simple passive integrator is shown in figure 8-17. When switch S is closed, capacitor C charges as shown. If switch S is now opened as shown at time tl, the charge on C and hence Eout remains at the level achieved before switch S was opened. Integrating amplifier A1002 operates in exactly the same manner as the passive integrator. The amplifier, in addition to inverting the output polarity, has the effect of multiplying the input signal and the time constant by the gain of the amplifier, thereby achieving a more nearly linear charging curve than that shown in figure 8-17. The reference center about which the d-c voltage varies is established by a 150-volt reference potential from a voltage divider in A1001. This level is preset prior to EFC search, so that the search centers about 30 MHz.

As stated previously, the EFC loop is closed when the frequency difference between the local oscillator output and the transmitted pulse is within the pass band (approximately 25 to 35 MHz) of the IF amplifiers in the EFC control unit. For example, if the difference frequency is above 30 MHz, negative pulses are coupled out of the frequency discriminator. These pulses are fed into the video amplifier and pulse stretcher (A1001), where negative pulses are developed, proportional in amplitude to the frequency deviation above 30 MHz. The negative stretched pulses are applied to integrator A1002, which causes the d-c output to integrate to a less negative voltage. This voltage, applied to its reflector, drives the local oscillator to a lower frequency. Thus the EFC circuit constantly adjusts the local oscillator frequency to compensate for changes in the magnetron frequency.

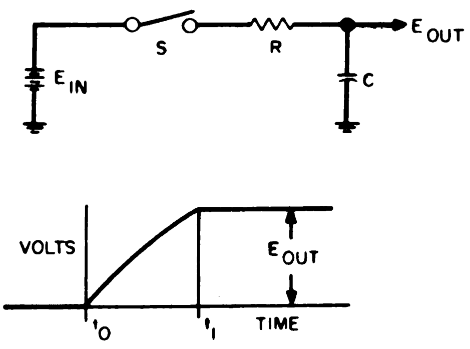


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Figure 8-17.–Simple passive integrator.

Automatic control of the receiver gain is required for normal operation of the range and angle tracking circuits. Signal level can be maintained for return signals varying in strength from 1 milliwatt down to one ten-thousand-millionth of a milliwatt.

The radar has two receiver channels, the narrow band and the back bias, and the AGC system has capabilities for controlling the gain of both these channels. The back bias receiver has two AGC control loops, the signal AGC and the noise AGC. The signal AGC is used to control the gain when a target is being tracked and the noise AGC is used to provide gain control in a clutter environment or in the presence of certain types of jamming.

In addition to providing automatic gain control of the receivers, the AGC system performs the following functions:

1. Detects target amplitude modulation (angle error signal) for use by the angle tracking circuits.
2. The signal AGC, the output of which is a function of the target amplitude, derives its information from the target detector, and its output controls the operation of lockon circuits in the range track system.
3. The power level mode switch is controlled by the output of the narrow band AGC. This output is proportional to the signal strength of the target being tracked. When this signal exceeds a predetermined level, the power level mode switching circuits are transferred from narrow band to back bias operation.
4. One output of the noise AGC serves as the input for the HOJ-AOJ detector. When the noise AGC level exceeds a predetermined value, the radar automatically transfers to HOJ operation.
5. Portions of the AGC circuits provide manual gain control in search.

Vertical Reference System

The vertical reference system (fig 8-18) is a simplified block diagram of the vertical reference roll channel. The climb and roll channels operate alike; therefore, only the roll channel is described here.

In level flight, the gyro roll synchro transmitter output to the stator of roll control transformer B5003 is such that there is no voltage induced in the B5003 rotor. Thus, no voltage is applied to roll magnetic amplifier A4901. During aircraft maneuvers, relative motion between the gyro gimbals and the aircraft cuases voltage proportional to the angles of displacement involved to be induced in the transmitting synchros. The output of the roll synchro transmitter is now such that the rotor of roll control transformer B5003 is no longer in the zero output position. As a result, there is a voltage applied to magnetic amplifier A4901. The signal is amplified in A4901 and applied to roll servomotor B5001. Roll servomotor B5001 drives the rotor of B5003 in a direction to minimize the output; B5001 also drives the gearbox and roll dial to indicate the amount of displacement. This action continues until the output of B5003 is zero.

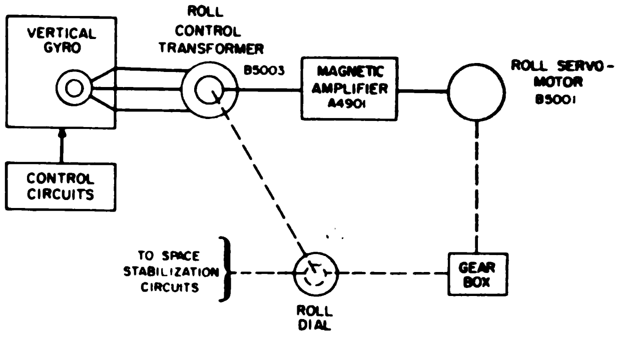

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Figure 8-18.—Vertical reference system, block diagram.

In the manner described in the preceding paragraph, the roll dial and the roll shaft are deflected an amount proportional to the aircraft deviation from level flight in the roll axis. Simultaneously, the roll shaft positions the resolvers and induction potentiometers used for space stabilization in roll. The resolvers are so positioned so each may be considered a part of an individual subsystem. They are parts of the antenna stabilization subsystem, B-sweep subsystem, and artificial horizon line subsystem.

In straight and level flight, the principal axes of the vertical gyro are alined with the aircraft so that the roll axis is parallel with the longitudinal axis, the climb axis is parallel with the transverse axis, and the spin axis is parallel with the vertical axis. An erection system is provided to orient the gyro spin axes on a line passing through the center of the earth. Erection is to compensate for errors resulting from rotation of the earth, motion of the gyro with respect to the earth, and gyro drift.

The spin axis is oriented by gravity-sensitive devices. The gyros have a bubble-type electrolytic vertical-reference device mounted on the inner gyro gimbal. Displacement of the sensors mounted within the gyro causes the bubbles in the sensors to move off center, and applies corrective voltages to torque coils mounted along the climb and roll axes. The torque coils reposition the gyro gimbals until the spin axis is once more alined with the gravitational field of the earth. At this time, the sensor bubbles are centered and corrective torque removed.

The bubble-type electrolytic gravity sensors should be affected only by gravity for ideal operation. However, other accelerations, the result of aircraft speed changes or maneuvers, also affect the sensors. To avoid excessive erection errors, any maneuver sufficiently violent to produce excessive error in the sensors actuates a cutout of error signal. The cutoff removes erection of excessive acceleration in the plane, placing the gyro in a state of free drift until the excessive acceleration is no longer present. The gyros have a cutout in the roll plane only.

After prolonged maneuvers, the vertical gyro can drift sufficiently to cause an abnormal presentation upon return to normal flight. As such times, the radar intercept officer can hold the GYRO switch at FAST to rapidly restore the horizon line to normal. By this method, initial erection voltage is applied to the torque motors for as long as the GYRO switch is held at FAST.

Mode And Track Switching Circuits

The mode and track switching circuits provide automatic and semiautomatic means of transferring the radar system from one mode of operation to another. The various modes of operation and the switching required for each mode are described in the following paragraphs.

SEARCH.–During search operation the switching circuits provide an automatic antenna scan pattern and manual control of the range tracking system. The switching circuits also provide a search display on the indicators and allow the RIO to control and select the desired radar functions. The RIO selects the antenna scan pattern by means of switches on the radar set control and adjusts the azimuth and elevation coverage of the scan pattern with the radar control stick and the elevation control wheel on the antennna control. The RIO also can select the range displayed on the indicator, the receiver channel in use, and the type of polarization of the transmitted energy. During search, the switching circuits provide manual control of the radar receiver gain. The RIO adjusts the gain by means of a front panel control on the radar set control. When the system is in radar, boresight, or map mode and the range displayed is 10, 25, or 50 miles, an acquisition symbol is displayed on the radar indicator. The azimuth and range positions of this symbol are controlled by the radar control stick. The map mode is like the radar mode, except that the elevation coverage of the antenna is reduced and circular polarization, if selected, is removed. In the boresight mode, the switching circuits remove the antenna scan pattern and manual control of the antenna, and point the antenna dead ahead to allow the pilot to conduct an optical attack in case of radar malfunction.

ACQUISITION.–Complete acquisition of a target by the radar system is possible only in the radar and map modes, and only in the AI ranges. In the boresight mode, it is possible to acquire a target in range only. The radar intercept officer starts the acquisition process in the radar or map modes by bracketing the target dot with the acquisition symbol and pressing the lockon switch to half action. The lockon switch initiates a relay sequence which transfers the antenna to manual control and provides a range strobe on the indicator B-sweep. When the range strobe and the acquisition symbol have been adjusted on the target, the RIO presses the lockon switch to full action and the system attempts to lock on the target automatically. If a target is present within the tracking gate, the target detector and lockon circuits detect the presence of the target and initiate a relay sequence which transfers the system to track operation. The affected relays remove the manual control inputs from the range and angle track systems, and supply received target information to these circuits for automatic tracking. The relays also provide a track display on the radar indicator.

PILOT LOCKON MODE.–The Pilot Lockon Mode (PLM) provides the pilot with the ability to initiate target acquisition and lockon. It also provides for his priority for control of the radar. PLM is initiated by the pilot pressing his target acquisition enable switch to half action. This commands the antenna to boresight, and selects a 5-mile range B-sweep presentation on the indicator displays. Flying a pursuit course, he presses the target acquisition enable switch to full action when he judges the target to be on boresight. After a short time delay, the full-action signal is transmitted to the synchronizer target detector and tracking circuits. Simultaneously, a range sweep strobe signal is generated that sweeps the range gate in the tracking circuits through the 5-mile range. When coincidence occurs in time between the range gate and the target video, range lockon occurs followed immediately by angle track. Target rejection can be accomplished by either the RIO or pilot by switching to half action momentarily.

TRACK.–After the target has been acquired, the system is in track operation, and it remains so until the target is manually rejected or until the target return is lost. During this time, the range track circuits provide target range and range-rate information to the computer for attack course computations. If the target return fades while the system in the radar mode, the lockon circuits deenergize the relay that initiated the lockon sequence, but a time delay prevents the remainder of the relays from deenergizing until 5 seconds later. If the target reappears in the tracking gate during this 5-second period, the system resumes tracking; but if the target does not reappear, the switching circuits transfer the system to search operation. If the target reappears outside the tracking gate during the 5-second period (target not at the same range as the range strobe), the RIO can reacquire the target without losing angle track by pressing the lockon switch to half action, repositioning the range strobe over the target, and pressing the lockon switch to full action. The system then reacquires the target in range. In normal radar track operation, the switching circuits also allow range track to be transferred to a target at a different range without placing the entire system in search. To do so, the RIO presses the lockon switch to half action. If the system has been tracking, the range track circuits are transferred to manual control and the angle track circuits operate on memory. The RIO then positions the range strobe on the desired new target and presses the lockon switch to full action. The system then reacquires the new target in the normal manner. When the interceptor-to-target range is less than that required for a successful engagement, the computer provides a breakaway signal to the switching circuits which cause a breakaway-X to be displayed on the radar indicator.

HOME ON JAM.–If a target that is being tracked in the normal manner operates a noise or CW jammer that obscures the target return, the switching circuits automatically transfer the radar to HOJ operation. The jamming signal is detected by the HOJ/AOJ detector, which monitors the back bias noise AGC and the CW signal level in the back bias IF amplifier. A relay energized by the HOJ/AOJ detector transfers the system to HOJ operation, as shown by the HOJ light on the RIO indicator. The HOJ relay circuits are interlocked by the normal lockon circuit to prevent HOJ operation if the target is not obscured by the jamming. The HOJ relay circuits transfer the range track circuits to memory operation to supply predicted range and range-rate information based on the last known range rate and range of the target. The angle track circuits automatically track the jamming signal in angle and provide this information to the computer. If jamming ceases during HOJ operation and the predicted range is at the correct value, the switching circuits automatically transfer the system back to normal tracking. If the predicted range is not correct when the system transfers back to normal operation, the system remains locked on for 5 seconds, allowing the operator to relock on the new target range. After 5 seconds, the radar unlocks and returns to search. Relock on the target can be attempted if target burn-through occurs and the system remains in HOJ operation. Relock from HOJ is the same as relock from normal track, except that the jamming signal might be present. If there is a jamming signal when the RIO presses the lockon switch to half action, the angle track circuits continue to track the jamming signal while the RIO manually adjusts the range strobe on the target. When the target is acquired, the system transfers to normal tracking. If the target is not acquired, the system transfers to AOJ operation, since the range memory is destroyed.

ACQUISITION ON JAM.–If a jamming signal is encountered during search operation and the target return is obscured, acquisition and lockon can be accomplished on the jamming signal to provide system angle tracking only. The presence of the jamming signal is detected by the HOJ-AOJ detector, allowing the AOJ relay to energize during acquisition. As a result, the system is in the AOJ tracking condition and angle tracking is established on the jamming signal. Since no target range information is received by the system, the range tracking circuits are not used during AOJ. If the jamming signal ceases during AOJ tracking, the switching circuits automatically transfer the system back to the search mode. Under certain conditions it is desirable to prevent AOJ operation. For this result the TRACK switch is set in the AOJ OUT position, so that the AOJ relay cannot be energized by the switching circuits.

MANUAL TRACK.–The switching circuits provide a means of tracking the target manually when the TRACK switch on the radar set control is set at MAN. At this time range lockon is not possible; when the lockon switch is pressed to half action, the system is in complete manual control. The antenna is manually positioned to illuminate the target, and the range strobe is positioned at the desired target range. When the lockon switch is pressed to full action, the system switches to manual track operation. In this condition, the angle track system remains under manual control and range-rate information is supplied by the MAN Vc potentiometer on the radar set control. This manual range-rate voltage is supplied to the computer and is integrated by the range circuits to provide range voltage changes. For adjustment of this control the RIO observes the relative movement between the target video and range strobe on the indicator B-sweep. Automatic angle tracking can be attempted at this stage; for this purpose the RIO positions the range strobe directly over the target and presses the MAN Vc control. A switch on this control provides the switching signal necessary to lock up the angle track circuits. The ANGLE LOCK light on the radar set control lights to indicate the switch position. In automatic angle track, the range strobe must be kept on the target at all times so that the angle track circuits can receiver proper angle track information. Otherwise the antenna might drift off the target.

DATA LINK.–Circle-dot data link operation provides the capability for pursuit of a target that is beyond the operating range of the radar system. The target is tracked by a ground based radar installation. Target position, direction of flight, and speed are compared with the position and speed of the interceptor at the same instant. This information is received and converted to analog form and is then displayed on the radar set by means of two symbols; the data link circle and data link dot. Data link operation makes it possible for the interceptor to approach the target closely without announcing its presence, since it is not necessary for the interceptor radar to be transmitting at this time. Once the target is within the effective operating range of the fire control system, normal radar acquisition and tracking can be resumed. During data link operation, a 28-volt data link signal is sent to the indicator control to provide the relay switching necessary to present the circle-dot display. No other switching in the radar set is required to provide data link operation.

SIDEWINDER EXTENDED ACQUISITION MODE (SEAM).–This mode provides target designation information to the selected AIM-9 missile by utilizing radar information. In SEAM operation, the missile head seeker may be slaved to the radar antenna when the radar set is in the track mode and a circle-dot displaying this information appears on the radar indicators. This is accomplished by the visual target acquisition set (VTAS) in conjunction with relay switching in the indicator control. To acquire a SEAM lock, the seeker head must be within 3° of the radar antenna lock angle when the radar set is in the track mode and the AIM-9G missile audio-tone must be above a preset threshold. A SEAM dot and a circle representing 20° of angular displacement from boresight are displayed on the indicators after AIM-9G seeker lockon. SEAM dot displacement from the center of the display indicates the seeker head angular displacement from boresight, but the dot displacement is only linear out to 10° (approximately 0.3 inches). Radar displays which will not be present during the SEAM display are: Data link circle and dot, ASE circle and dot, search and acquisition displays and the break-X symbol. Relay switching in the indicator control disables the data link mode and removes the break-X display capability when in SEAM.

Range Tracking System

The range tracking system automatically determines the range separation between a particular target and the radar. In addition the range tracking system selects the desired target for angle tracking from among other targets that happen to be at the same azimuth and elevation bearing but at different ranges which could cause angle track on the wrong target.

The discussion of range tracking circuits described in the following paragraphs is divided into three divisions as follows:

1. The rudimentary tracking loop, which describes the fundamentals of range tracking operation.
2. The simplified range tracking operation, which establishes the tracking gate relationships.
3. The dual-channel tracking loop which introduces the switching and time relationships which occur with the use of the narrow band and back bias amplifiers.

RUDIMENTARY TRACK LOOP.–The range to a target is determined by a precise measurement of the time it takes for the transmitted RF energy to travel to the target and return. Radar range is therefore proportional to time: the time to travel 2,000 yards and return (1 radar mile) is 12.36 microseconds. However, since the range track output must be a d-c voltage proportional to range, a means to relate time to voltage is required. The time modulator makes this conversion, as follows:

1. At the instant the transmitter fires, a trigger is sent to the time modulator to start the range sweep.
2. As can be seen in figure 8-19, for any time after t_0 the range sweep is at some definite voltage. For example, at 150 microseconds after t_0 (24,580 yards) the range output is equal to 49 volts.
3. The range sweep voltage is compared with the d-c range voltage, and when the two are equal the comparator generates a pulse.
4. This pulse is applied to the gate generator, which produces a tracking gate (fig. 8-20).
5. The tracking gate is applied to the time discriminator, where it is compared in time with the actual video return from the target. If the range voltage is correct, the tracking gate arrives in the time discriminator at exactly the instant the target video arrives. If the range voltage, and hence the gate time position, is not exactly correct, there is an error in alinement between the tracking gate and the video return from the target. This misalinement produces an output from the time discriminator error detector, which is applied to the d-c integrators to correct the value of the range voltage so as to reposition the range gate (tracking gate) to be precisely in time with the target video.

SIMPLIFIED RANGE TRACKING OPERATION.–The principles of operation of the time discriminator and the various gates are discussed in the following paragraphs. Figure 8-21 shows the time discriminator and the application of the selector gates.

It is desirable to exclude extraneous returns such as clutter and jamming from the error detector. Only the video information present at the desired target position in range is sent to the error detector. By this means undesired signals are prevented from affecting the tracking performance, except for the very brief period when the target is present. Exclusion of undesired signals is accomplished by gating the video, the effect of which is shown in figure 8-22.

The error detector operates on bipolar video, generated by sending the video down a short-circuited delay line whose delay time is equal to the video pulse width. The original pulse is reflected, inverted, and delayed, as shown in figure 8-23.

As shown in figure 8-21 the bipolar generator consists of a delay line driver amplifier and the short-circuited delay line. The error detector, which is gated, has an output proportional to the tracking error. Figure 8-22 shows the tracking gate perfectly alined with the bipolar video, and the positive and negative portions of the bipolar video equal. Hence the output of the error detector is zero. Figure 8-24 shows the tracking gate misalined with the bipolar video. In this case the tracking gate intercepts a larger portion of the positive part of the bipolar video

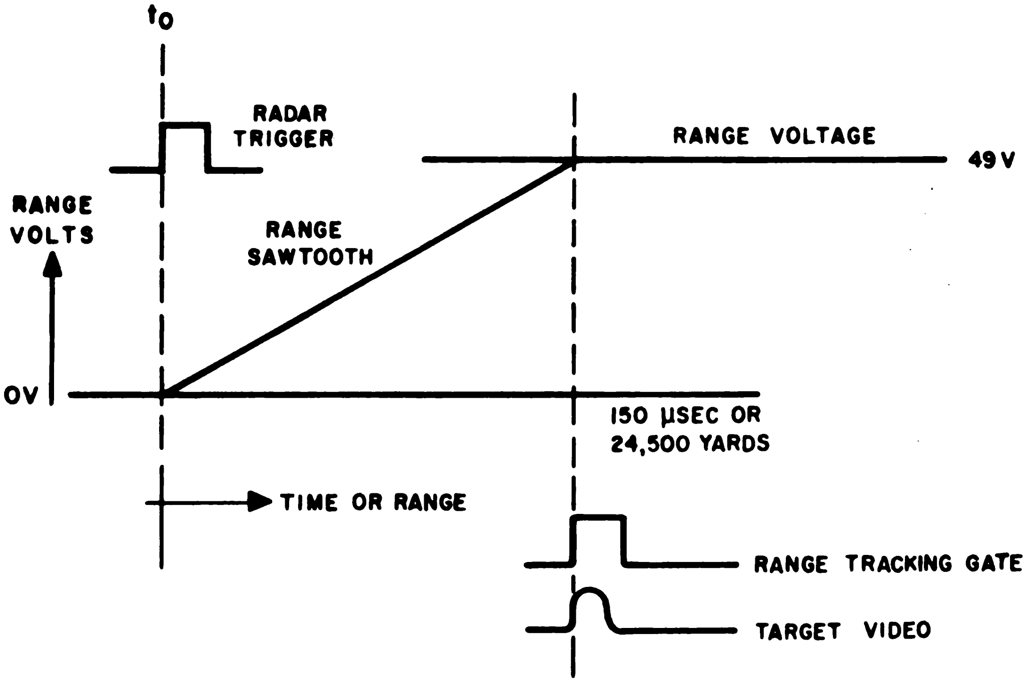

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Figure 8-19.—Development of tracking gate.

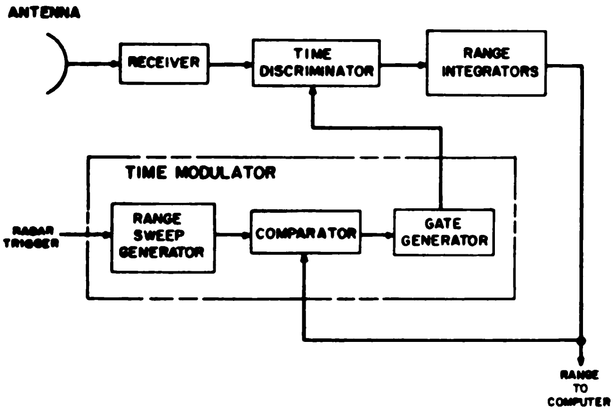

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Figure 8-20.—Rudimentary track loop, block diagram.

than the negative, so that there is a net positive output signal from the error detector for application to the range integrators.

As previously described, the error signal is of the polarity to correct the range voltage and bring the output of the error detected back to zero.

The time selector gate, tracking gate, gated video, and bipolar video have a definite time relationship, which is shown in figure 8-22 for a target 2 microseconds wide, assuming perfect tracking. The 1-microsecond delay, produced by a delay line (fig. 8-21), is required for correct alinement of the tracking gate with the center of the bipolar video.

DUAL CHANNEL TRACK LOOP.—The dual channel range track loop receives video from either the narrow band amplifier or the back bias amplifier. The maximum detection and

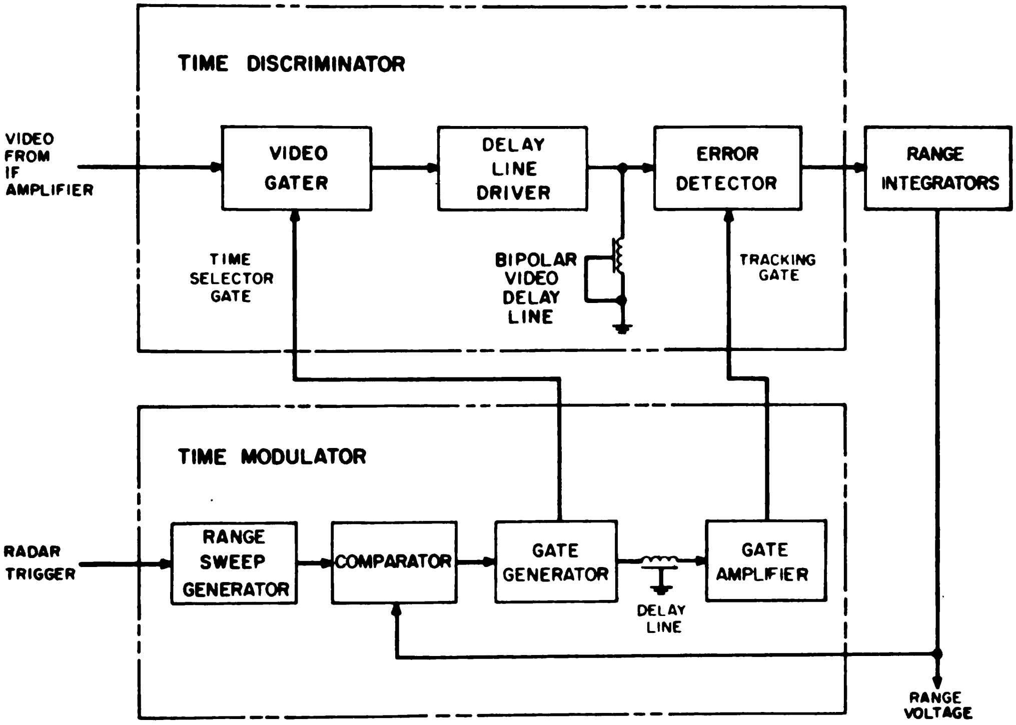

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Figure 8-21.—Simplified range track operation, block diagram.

tracking range is obtained in narrow band operation.

In narrow band operation a 2.0-microsecond pulse is transmitted, and therefore the video pulse to the range tracking circuits is 2.0 microseconds wide. In back bias operation, the transmitted pulse is only 0.4 microsecond wide. Back bias operation provides greater immunity to interference; but the back bias IF amplifier operates on the return signal, so that the target video is not a conventional, smoothly shaped pulse as obtained from the narrow band IF amplifier.

If tracking is initiated in the narrow band channel and the signal return exceeds a predetermined level at which tracking may be maintained in the back bias channel, the range tracking system automatically transfers to back bias operation, with the advantage of immunity from interference. The transfer operation is controlled by the power level mode switching circuits.

Angle Tracking System

The purpose of the angle tracking system is to maintain the radar antenna pointed at the desired target. Target bearing and angular rate with respect to the aircraft are thereby provided to the computer of the CW radar system. Target position is also presented to the radar intercept officer and the pilot by means of the display system. When the antenna is thus oriented, it can illuminate the target with the CW RF energy required to guide the Sparrow III missile.

In normal operation the angle tracking system uses the conventional pulse-radar angle-tracking scheme with conical scanning. However, in the

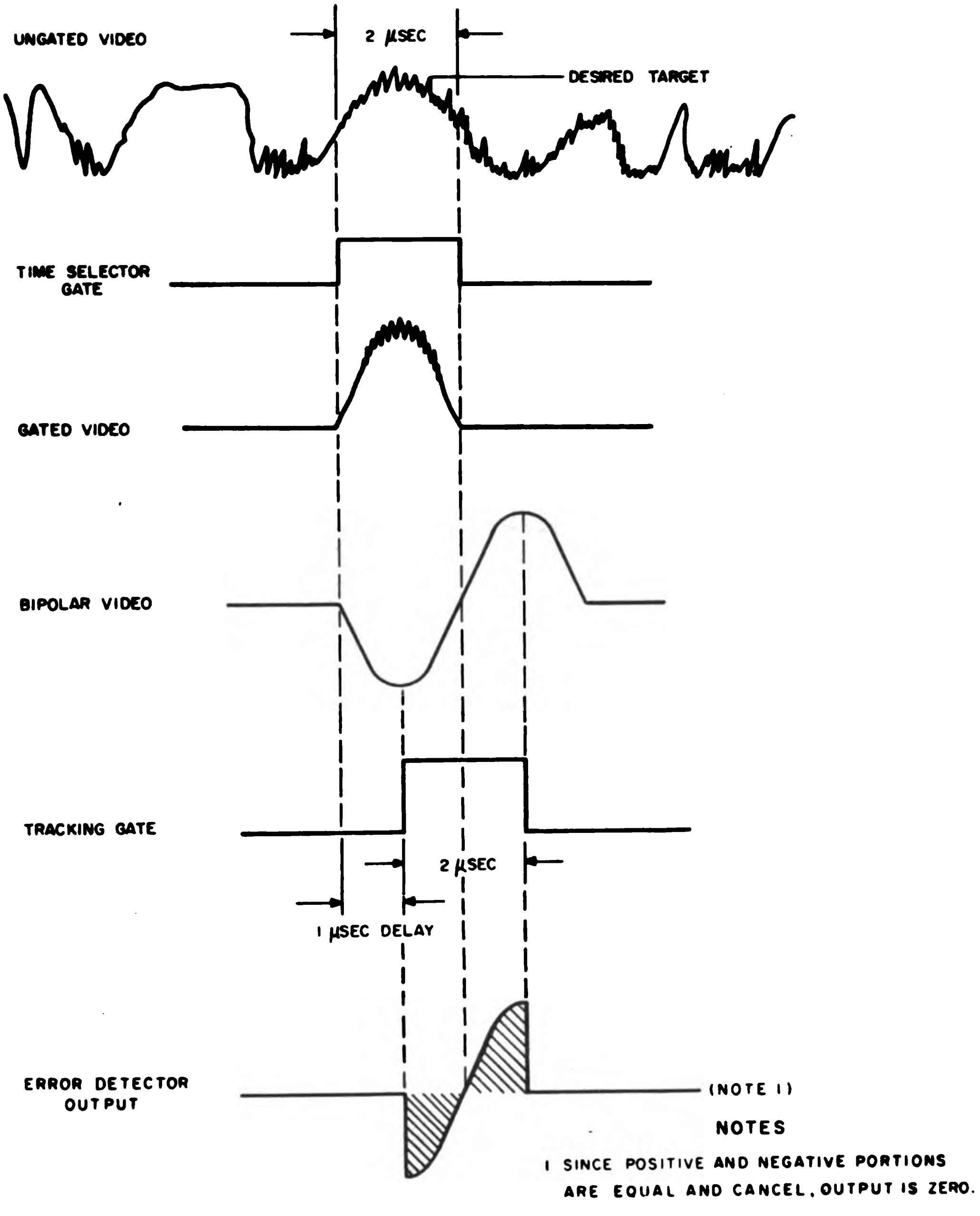

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Figure 8-22.—Video and error detector gate.

event that certain forms of jamming signals are transmitted by the target aircraft, the angle tracking system automatically continues tracking, using the jamming signal itself to provide the required target information. In the following presentation of the general theory of the angle tracking system, the basic idea of angle track operation is first considered. A rudimentary

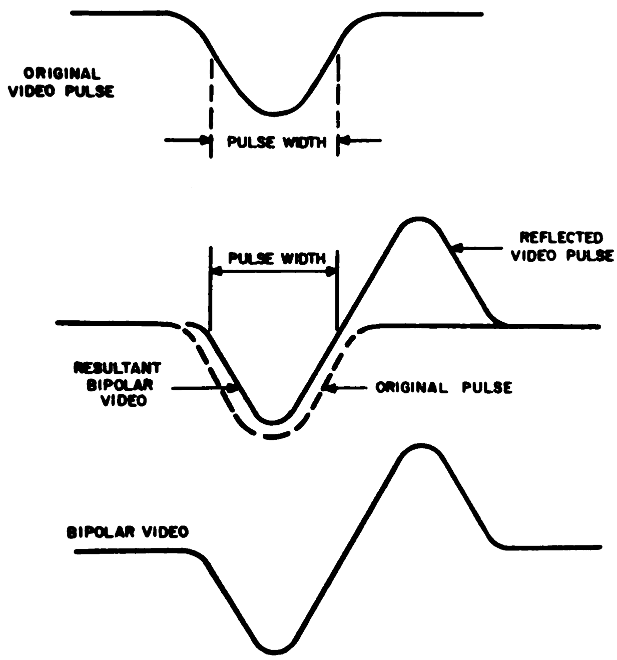

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Figure 8-23.—Development of bipolar video.

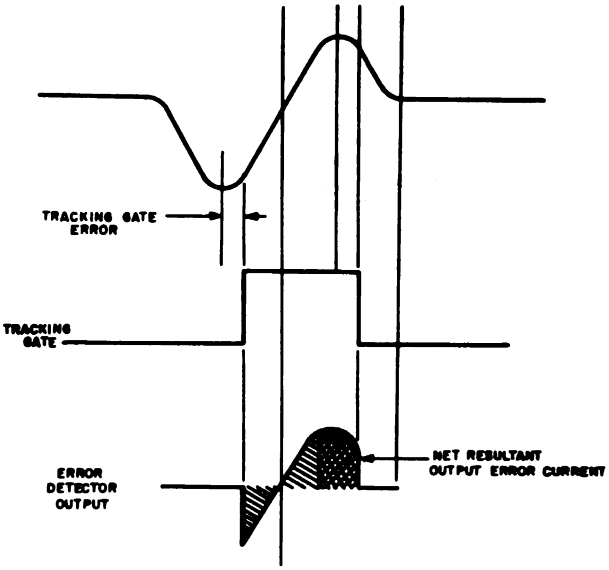

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Figure 8-24.—Misalinement of tracking gate and bipolar video.

angle track loop is then discussed, and finally the complete angle track loop as actually encountered in the intercept radar is presented.

BASIC ANGLE TRACK OPERATION.—In order to obtain target position information, the radar antenna feedhorn is positioned slightly off center, and rotated at approximately 3,600 rpm. The mechanical offset causes the direction of the pencil-shaped radar beam to deviate slightly from the antenna centerline and the rotation of the feedhorn causes the beam to rotate as shown in figure 8-25. This rotation is called nutation, and the resulting pattern is called conical scanning. Any target along the centerline of the pattern, such as target A in figure 8-25, receives uniform radar illumination as the beam rotates. Consequently return energy from target A is of constant amplitude; that is, there is no amplitude modulation.

Any other target such as target B will receive maximum illumination when the beam is directed toward it (position 1) and minimum illumination when the feedhorn has rotated 180° from this position (position 2). The return energy from this target is amplitude-modulated in accordance with the lobing pattern of the radar beam. The amplitude of the modulation is proportional to the angular deviation from the centerline (angle error), and the phase of the modulations is related to the position of the target with respect to antenna coordinates. Figure 8-26 shows this target video as detected in the radar receiver. The modulation shown is 180° out of phase with the elevation reference signal representative of a target directly above the antenna centerline, like target B in figure 8-25. This modulation is then detected to produce the composite angle track error signal and applied to the angle track circuits, which resolve the error signal into its azimuth and elevation components. These components are applied to the antenna drive circuits to reposition the antenna so as to eliminate the error. For the example shown in figure 8-26, a resultant

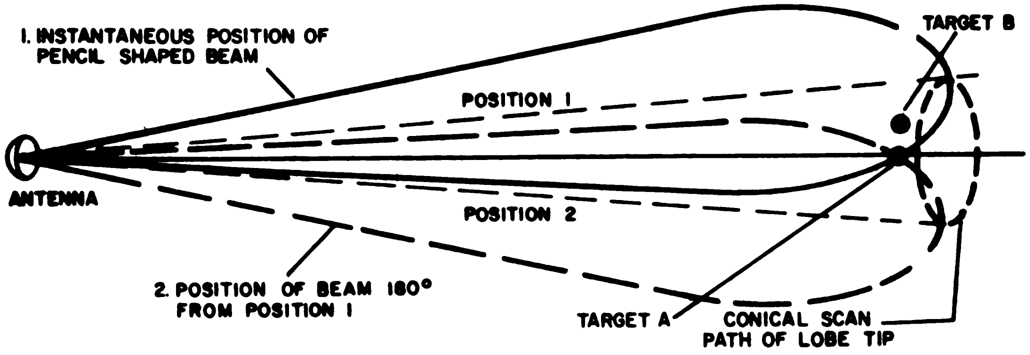
1. INSTANTANEOUS POSITION OF PENCIL SHAPED BEAM
TARGET B
POSITION 1
ANTENNA
POSITION 2
2. POSITION OF BEAM 180° FROM POSITION 1
TARGET A
CONICAL SCAN PATH OF LOBE TIP

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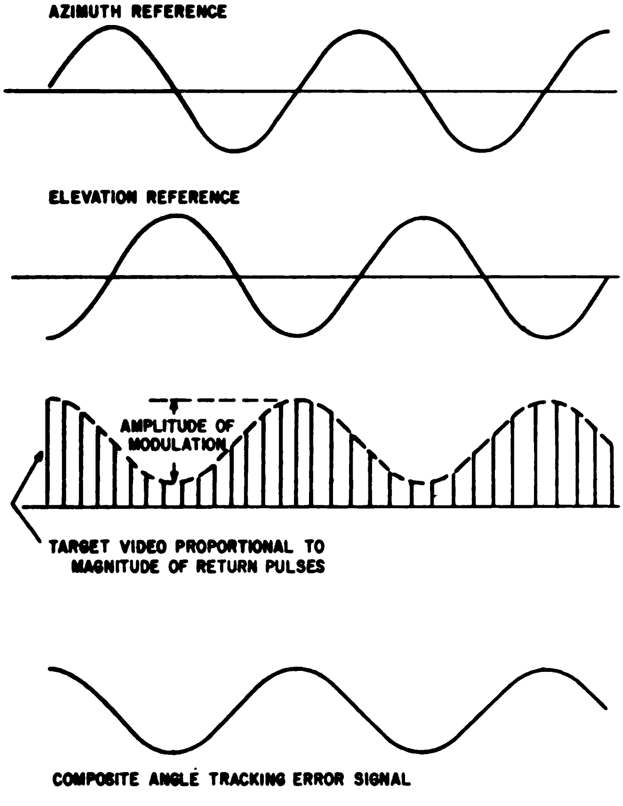
Figure 8-25.–Conical scan pattern.

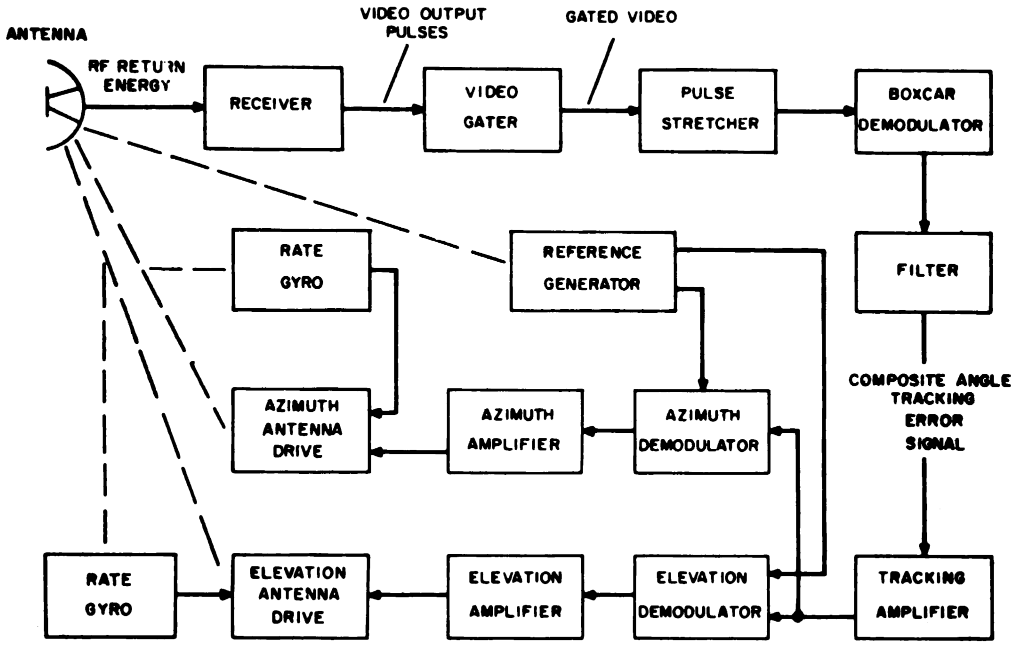

AZIMUTH REFERENCE
ELEVATION REFERENCE
AMPLITUDE OF MODULATION
TARGET VIDEO PROPORTIONAL TO MAGNITUDE OF RETURN PULSES
COMPOSITE ANGLE TRACKING ERROR SIGNAL

AQ.284
Figure 8-26.–Target video waveform.

output will be obtained in the elevation channel of the track demodulator. This output is the antenna command signal that drives the antenna upward toward alinement with the target.

This detected amplitude modulation of return pulses is the composite angle tracking error signal. It is the input to the angle tracking system. The composite angle tracking error signal is demodulated with respect to the horizontal and vertical reference voltages as shown in figure 8-26. The reference voltages are obtained from the reference generator rotated by the antenna feedhorn spin motor. The angle track demodulator circuits resolve the error into azimuth and elevation antenna drive signals.

RUDIMENTARY ANGLE TRACK LOOP.–A block diagram of a rudimentary angle tracking circuit is shown in figure 8-27. The RF return energy, modulated as a function of the tracking error as described previously, is received by the antenna and sent to the receiver. The receiver detects the amplified signal to produce a video output. The video is then gated at the target range so that only the modulation from the desired target is applied to the angle track circuits. The gated video is then stretched to approximately 100 microseconds and applied to the boxcar demodulator, which derives the composite tracking error signal from the amplitude modulation on the video. This output is



AQ.285
Figure 8-27.—Rudimentary angle track system, block diagram.

filtered to remove extraneous switching transients, and is applied to the tracking amplifier.

The output of the tracking amplifier is sent to the azimuth and elevation coordinate demodulator. The 2-phase output of the reference generator, which indicates the instantaneous position of the antenna feedhorn, is applied to the demodulators. The composite tracking error signal is demodulated with respect to the reference generator output, so that the target error position in azimuth is obtained from the output of the azimuth demodulator and the elevation target error from the output of the elevation demodulator.. The demodulator outputs are applied to the azimuth and elevation amplifiers, which in turn are connected to the antenna drive circuits for each channel. Magnetic amplifiers in the antenna drive circuits control the hydraulic servo valves which control the hydraulic actuators on the antenna gimbals. To stabilize the gain of the antenna drive circuits and provide space stabilization of the angle tracking loop, rate gyro feedback is provided around the antenna drive.

COMPLETE ANGLE TRACK LOOP.—The angle track stabilization loop consists of the antenna drive circuits and the rate gyro feedback. The purpose of the stabilization loop is to isolate the angle track system from motion of the interceptor. The main tracking loop, as described previously, has a relatively slow response in order to provide noisefree tracking. However, should the interceptor engage in any rapid maneuver, the main tracking loop would not be capable of responding to the resulting error signal in time to prevent loss of the target. It is at this stage that the rate gyros come into play. The disturbance introduced by the aircraft maneuver represents an increase in the rate of motion of the antenna in space. Since the rate gyros develop outputs proportional to the rate of antenna motion, the change in motion causes the rate gyros to produce error signals tending to drive the antenna in the direction to maintain the desired tracking rate for the target.

For example, if an intercept run is being made on a target at the same altitude as the interceptor, the rate of motion of the antenna in elevation, commonly called line-of-sight elevation rate, is zero. Consequently the commanded rate from the intergrator and the actual rate of the antenna are both zero. If however, the aircraft pitches upward, tending to pull the antenna off the target, a line-of-sight rate is introduced into the rate gyro which is compared with the zero commanded line-of-sight rate. The resulting net error signal is applied through the magnetic amplifier to the antenna hydraulic circuits to drive the antenna down at such a rate as to cause the actual line-of-sight rate of the antenna to remain at zero and thus maintain tracking of the target.

The angle track system has three modes of operation: narrow band, back bias, and homing on jam (HOJ). In all modes of operation, the angle tracking signal is derived through the narrow band receiving channel. The difference between the narrow band tracking mode and the back bias tracking mode is in the method by which the target gating or target selection is made. If the radar is operating in the presence of certain types of jammers, the IF gating breaks up the jamming signal into discrete pulses which can then be detected by the rest of the tracking circuits, in the same manner as for the conventional target return. The angle track circuits then immediately begin to track the source on the jamming. If the jammer is turned off in an attempt to confuse the radar, normal tracking is resumed.

Angle Search System

The purpose of the antenna positioning servosystem is to direct the antenna so as to illuminate a particular area in which targets are sought. The area selected is determined by an automatically programmed scan pattern or manually by the radar intercept officer, or from the ground in data link operation.

The automatically programmed scan pattern is commonly identified with the search mode of operation, since in this mode the system is used to locate a target which can subsequently be locked on and tracked. The search pattern is a three-bar Palmer scan with a retrace on the center bar.

In data link operation the antenna positioning servosystem operates as in narrow scan with the exception that the data link channel, instead of the radar intercept officer, commands the position of the search pattern sector.

The RIO can point the antenna dead-ahead, that is, at zero azimuth and elevation. This mode of operation is used when the tracking radar is inoperative and it is desired to launch a missile optically. The aircraft is then flown on a pure pursuit course to maintain target illumination for missile operation.

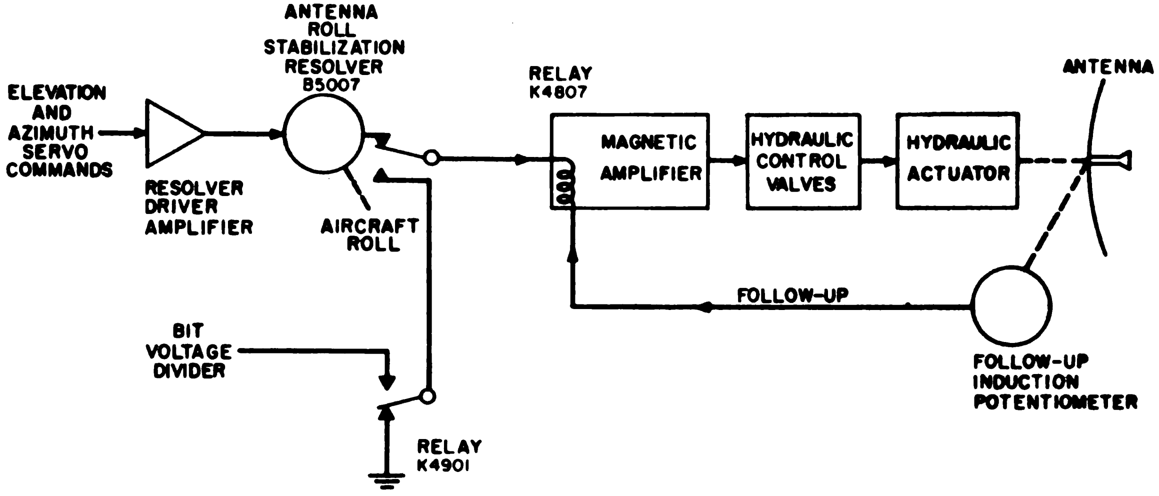
The command signal in the antenna positioning system, and hence the resulting antenna orientation is space-stabilized. As a result, if the antenna is positioned so that a target is detected while the aircraft is flying straight and level, the antenna will continue to be directed to the same position in space and the target will continue to be observed, even though the aircraft in the meantime is being put through extensive maneuvers.

The angle search system consists of the antenna positioning circuits, the servo command circuits, and the servo space stabilization circuit, each with an azimuth and elevation channel, as discussed in the following paragraphs. The azimuth antenna positioning servosystem is identical with the elevation antenna positioning system, except for the command inputs. A functional block diagram of the circuit for one channel is shown in figure 8-28.

Only the azimuth channel is discussed here. The desired antenna position is established by the command circuit, and the actual antenna position is determined by the induction follow potentiometer. The antenna command and follow voltages are both 400-Hz common phase signals. These signals are compared in the control winding of the magnetic amplifier; the difference between them is representative of the angular error between the desired antenna position and the actual antenna position.

The error signal is amplified by the magnetic amplifier to provide sufficient power to operate the hydraulic servo valve on the antenna.

The servo valve in turn controls the hydraulic pressure to the hydraulic actuator, which drives


ANTENNA ROLL STABILIZATION RESOLVER B5007
ELEVATION AND AZIMUTH SERVO COMMANDS
RESOLVER DRIVER AMPLIFIER
AIRCRAFT ROLL
RELAY K4807
MAGNETIC AMPLIFIER
HYDRAULIC CONTROL VALVES
HYDRAULIC ACTUATOR
ANTENNA
FOLLOW-UP
FOLLOW-UP INDUCTION POTENTIOMETER
BIT VOLTAGE DIVIDER
RELAY K4901

AQ.286
Figure 8-28.—Antenna positioning circuit, functional block diagram.

the antenna gimbal in such a direction as to nullify the error signal, thereby placing the antenna at the desired command position.

Display System

The display system of the intercept radar presents to the radar intercept officer and the pilot the information required to successfully accomplish an airborne intercept with the Airborne Missile Control System (AMCS). The radar return is displayed so that the target aircraft can be detected and acquired for automatic tracking. Once the radar is tracking the target, additional information required for the pilot to steer the aircraft and launch the missiles is presented on the display screen. Upon missile launch, the pilot is provided with the necessary information for maintaining target illumination to provide CW guidance for the missile.

The radar display system is also capable of operating in conjunction with ground-based radar installations, and displaying information received by a digital data communications set. The display data link symbols convey information as to the range, bearing, and altitude of the distant target, and direct the pilot on the course required for an intercept. Once the target is within the operating range of the radar and fire control system, the pilot can switch back to normal radar operation in order to complete the intercept.

The display system is described functionally as consisting of three independent channels: the A-gun channel, B-gun channel, and optical sight. The first two channels present search and tracking information to the pilot and radar intercept officer in the form of symbols generated electronically and presented on the screen of a display tube. The optical sight, however, is a mechanical-optical system that enables the pilot to visually intercept a target aircraft or bomb a fixed target.

The A-gun channel presents tactical and attack information; the B-gun channel is employed to display the B-type radar presentation for target detection, acquisition, and tracking. A ground mapping display, also presented by the B-gun channel, is available in the form of a B-type presentation. The presentations of the

A-gun and B-gun channels are both displayed on the screen of the same direct-view storage tube. Except for sharing the same viewing screen, however, the two channels operate independently and are therefore discussed in separate paragraphs. The optical-sight system provides a fixed reticle with angle depression control for optical attack and delivery techniques of the low altitude bombing system (LABS).

COMPONENTS OF THE DISPLAY SYSTEM. –The display system consists of all elements that directly contribute to the presentation displayed on the indicators. Signals are obtained from the climb and roll servos, antenna, range track system, receiver, and other components of the AMCS. The indicator control develops symbols, control voltages, and switching gates to convert the information received into the voltages required by the indicators. The RIO indicator contains a direct-view storage tube to display the A-gun and B-gun channel information. The direct-view storage tube (DVST) is capable of presenting a persisting display of the entire area being scanned by the radar antenna, whereas the conventional cathode-ray tube can only display the video returns momentarily as the antenna sweeps past a given point. A target embedded in noise can therefore be detected more easily on the DVST display, since the target return is illuminated in the same position during each sweep of the antenna; but the noise, which is random, usually does not appear in the same spot twice. The pilot's indicator also provides the A-gun and B-gun channel radar displays; but it differs from the RIO indicator in that it incorporates the optical sight system. The two indicators also contain power supplies, control circuits, and video amplifiers for the display tubes.

INFORMATION DISPLAYED.–The information displayed varies according to the operating condition of the radar. In search, many targets may be present on the display; in acquisition, one particular target is selected for attack. In track, the information includes aircraft guidance and attack directions. Accordingly, the information displayed is discussed separately under conditions of search, acquisition, and track operation.

Presentations during search are the composite A-gun and B-gun radar displays on the direct-view storage tube, and the optical sight display. The A-gun and B-gun composite search display (fig. 8-29) consists of a B-type presentation (range versus azimuth), a horizon line, and elevation strobe, and a radar acquisition symbol.

The type B presentation continuously displays radar target returns of the area covered by the antenna beam. The length of the two lines that make up the acquisition symbol indicates which range has been selected. The lines of the symbol appear approximately 1/8 inch long on the 5- and 50-mile range and 1/4 inch long on the 10- and 25-mile range. The range selection function is built into the radar control stick so that the RIO will not need to release his grasp on the radar control stick while attempting to acquire a target.

The azimuth position of the B-sweep on the B-gun display is determined by the antenna position with respect to the longitudinal axis of the aircraft, and is measured in a plane parallel to the earth's surface. The vertical sweep signal is obtained from a sweep generator in the indicator control and is synchronized with the radar transmitter. Target information obtained from the radar return signal is amplified in the radar receivers and video amplifiers, and the targets are displayed as blips of light on the B-gun display at their respective range and bearings. Vertical distance on the display screen, measured from the baseline, is proportional to target range; horizontal distance on each side of the center is proportional to the azimuth bearing of the target with respect to the longitudinal axis of the aircraft.

Acquisition is the process by which a target is selected and acquired for automatic tracking. When the desired target has been selected, it is then bracketed by the acquisition symbol and the lockon switch on the radar control stick is pressed to the half-action position. The antenna, which now operates under manual control, slews to the azimuth position of the acquisition symbol as indicated by the position of the B-sweep in figure 8-30. The range strobe appears as an intensified spot on the B-sweep during acquisition and track, and provides a more precise range indication than is possible with the acquisition symbol alone. The strobe is centered between the bars of the acquisition symbol, and

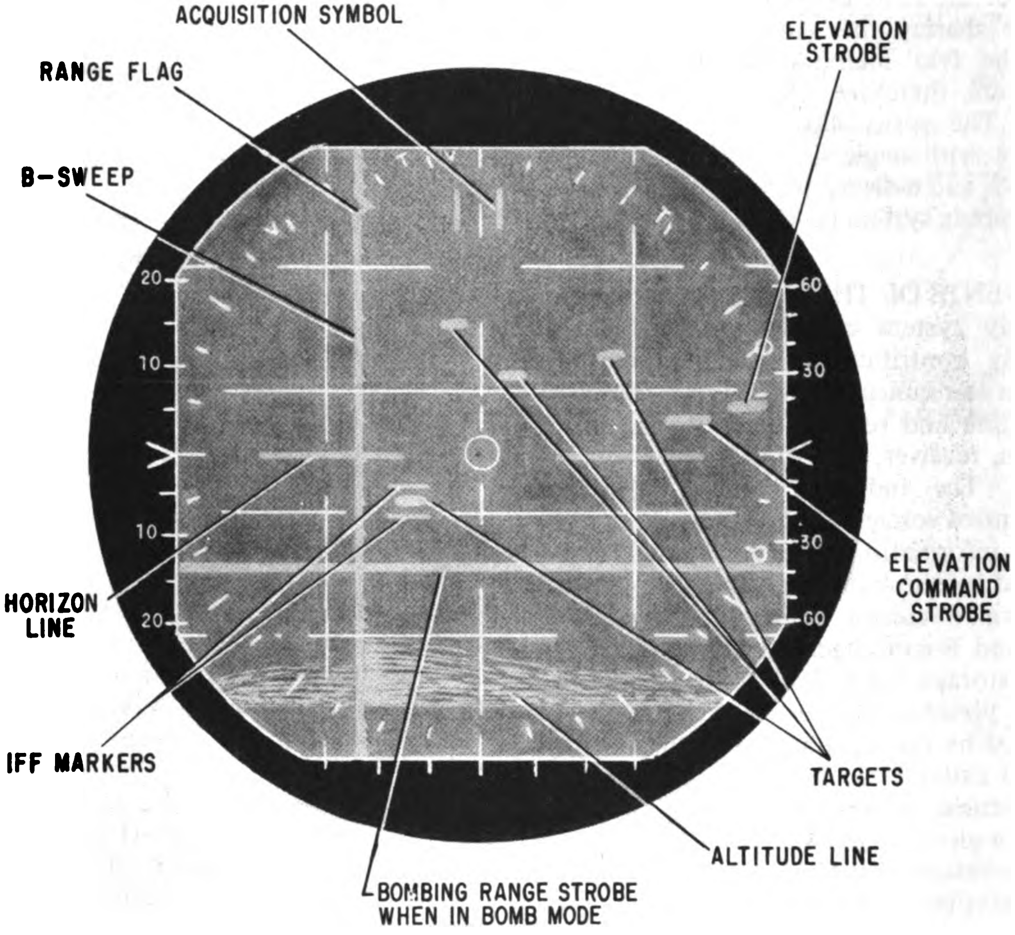


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Figure 8-29.—Composite A-gun display, search presentation.

the positions of both the strobe and the acquisition symbol are controlled by the radar control stick; the symbols are positioned in range by the forward movement of the radar control stick, and in azimuth by lateral movement of the stick.

When the lockon switch is pressed to full action, the range tracking system attempts to lock on the selected target. The presentation remains unchanged until lockon is achieved, at which time the track presentation described in the following paragraph is displayed.

When the RIO succeeds in locking on a target, the operation of automatic tracking is initiated. The acquisition symbol is removed from the display, but the remaining symbols discussed previously maintain the same functions as in the search and acquisition presentations. Several new symbols, unique to the track condition, are presented on the radar display. These include the range-rate circle, the allowable steering error (ASE) circle, the aim dot, and the R_a and R_{min} strobes. In addition, when the range strobe and target fall below the level of the R_{min} strobe, the track presentation is removed from the display screen and the breakaway-X symbol appears. These symbols are all explained in

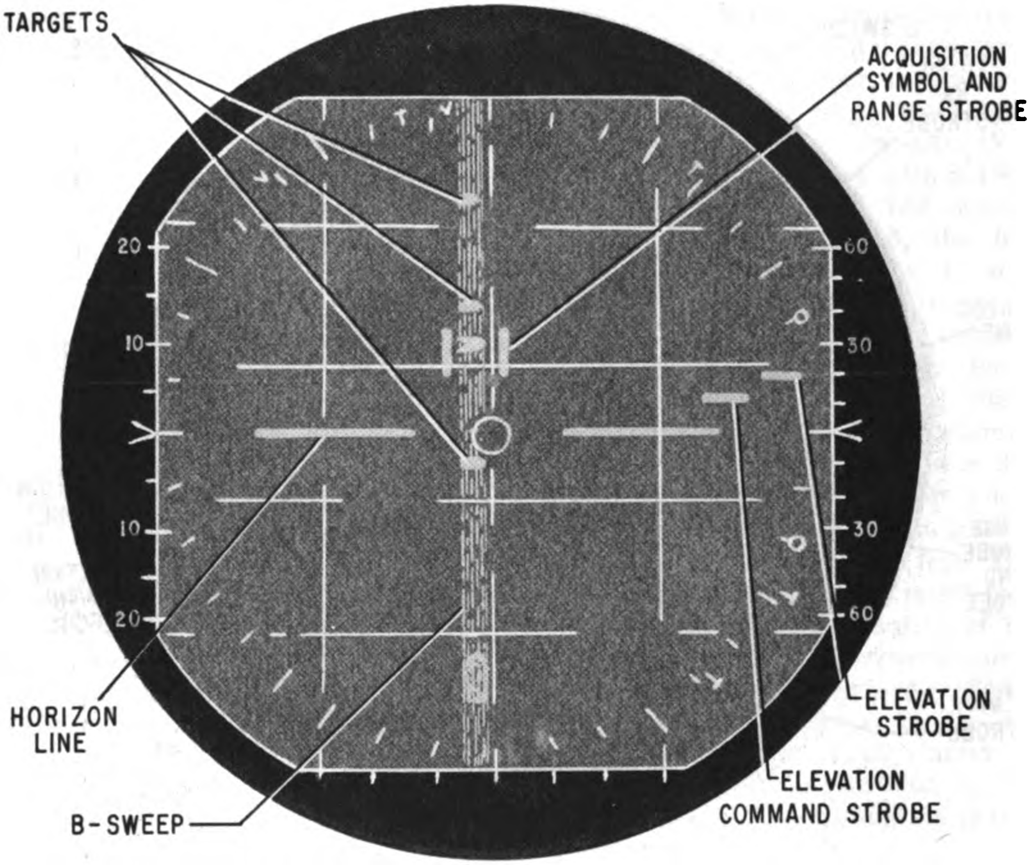

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Figure 8-30.—Composite A-B gun display, acquisition presentation.

detail later in this chapter. The elevation command strobe is present in track to allow the RIO to see where in elevation the antenna will point after the system is returned to search or acquisition. The composite A-gun and B-gun track presentation is illustrated in figure 8-31.

GENERAL DESCRIPTION OF A-GUN DISPLAY.—The following symbols are generated in the A-gun channel:

1. Search and track operation:
    a. Horizon line.
    b. Elevation strobe.
    c. Elevation command strobe.
2. Track operation only:
    a. Range-rate circle and gap.
    b. Allowable steering error (ASE) circle.
    c. Aim dot.
    d. Breakaway-X.
    e. Elevation command strobe.
3. Data link operation:
    a. Data link circle.
    b. Data link dot.
    c. Elevation strobe.
    d. Elevation command strobe.
4. SEAM operation:
    a. SEAM circle.

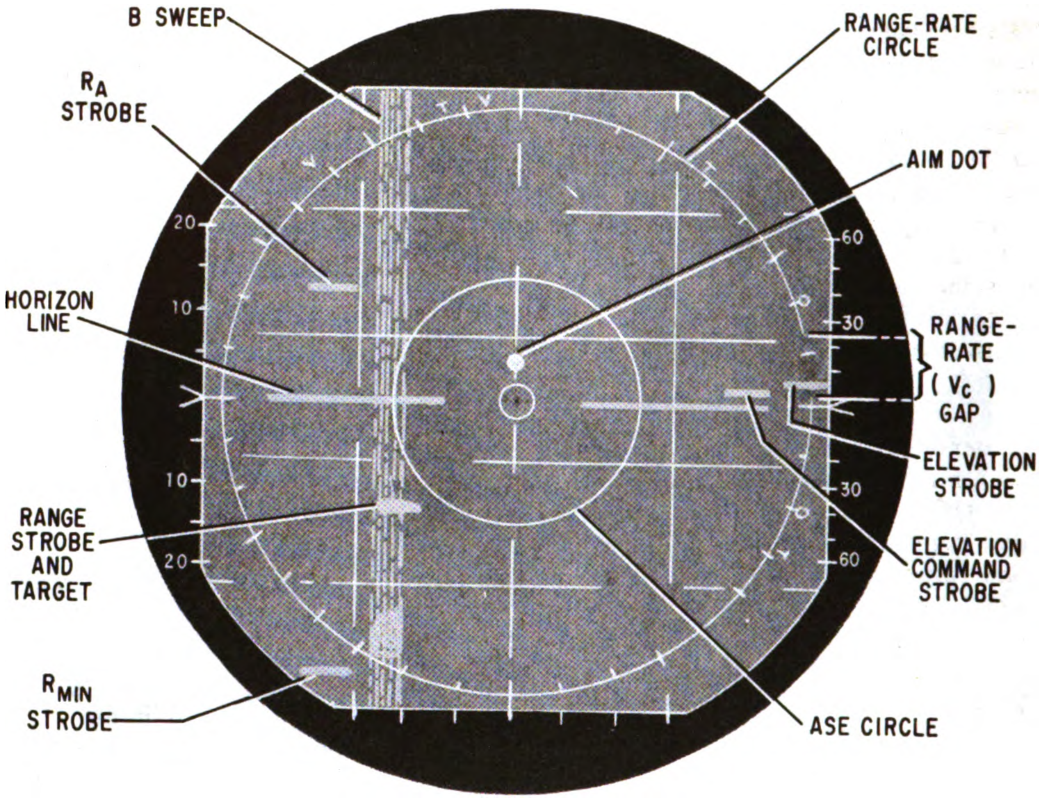

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Figure 8-31.—Composite A-B gun display, track presentation.

b. SEAM dot.
c. Range rate circle.
d. Elevation Strobe.
e. Elevation command strobe.

Figures 8-29 and 8-31 illustrate the search and track presentations, respectively, of the composite A-B gun display. Symbols shown on the illustrations which are not listed above, are generated by the circuits of the B-gun channel. These include the B-sweep, the target video and range strobe, the acquisition symbol, and the R_a and R_{min} strobes, and are discussed later.

The A-gun symbols are all produced in the same general manner. Appropriate signal voltages are applied to the horizontal and vertical deflection plates of the storage tube to form the symbol, and at the same time, discrete intensity pulses, adapted in amplitude and duration to the individual symbols, are applied to the intensity grid of the storage tube to illuminate the symbols. The various symbols are generated simultaneously and, by means of a time-sharing system, are displayed simultaneously by a single channel. The high persistence of the storage tube aids in the presentation by preventing the symbols from fading during the off periods.

During all operating conditions of the radar, the horizon line appears as a straight line across the display screen, with its center third blanked out. The purpose of the horizon line is to provide the pilot with a constant indication of the aircraft attitude with respect to the ground. The horizon line therefore duplicates most of the information presented by the artificial horizon of the aircraft attitude indicator mounted in the pilot's flight control panel, but this duplication is necessary because it permits the pilot to fly the aircraft during an intercept operation without being distracted from the radar display. When the aircraft rolls, the horizon line tilts according to the roll angle. Since a climb or dive angle is also measured with respect to the ground, this angle is therefore proportional to the displacement of the horizon line from the center of the screen in a direction perpendicular to itself (and to the ground). During level flight, the line is horizontal and in the center of the display screen.

The horizon line is generated by applying two sine waves, either in phase or 180° out of phase, to the vertical and horizontal deflection plates. These signals, referred to as the vertical and horizontal roll signals respectively, determine the length and slope of the horizon line. Two additional sine waves, whose amplitudes are proportional to the pitch (climb or dive) angle of the aircraft, are applied to demodulator circuits in the indicator control unit. The demodulated and filtered outputs of these circuits are added to the roll deflection signals as d-c levels which determine the pitch displacement of the horizon line.

The elevation strobe consists of a short horizontal line (approximately 1/4 inch long) displayed on the right side of the screen during all operating conditions of the radar. Its vertical position indicates the antenna elevation angle with respect to the horizon, which may be read, up to ±60°, on the elevation (EL) scale etched on the right side of the screen face.

The horizontal position of the elevation strobe is determined by the upper amplitude level of a 400-Hz square wave applied to the horizontal deflection plates of the storage tube. A small 20-KHz sine wave is superimposed upon the square wave to make the symbol appear as a short line rather than as a dot. A properly timed intensity pulse causes the elevation strobe to appear on the display during all conditions of operation.

The vertical position of the elevation strobe is determined by a 400-Hz sine wave input, the amplitude of which is proportional to the elevation angle of the radar antenna. This signal, after being demodulated and filtered, is applied to the vertical deflection plates during the time interval that the half of the square wave representing the elevation strobe horizontal position is applied to the horizontal deflection plates.

When a target has been acquired and the radar begins automatic range tracking, the fixed 3 1/4-inch diameter range-rate (Vc) circle is presented on the display with a 1/4-inch range-rate gap in its perimeter. The circle merely acts as a carrier for the gap, the instantaneous position of which indicates the relative speed (range rate) between interceptor and target. When a constant range is being maintained between interceptor and target, the range rate is zero and the gap appears at the 12 o'clock position (called the zero position). Clockwise displacement of the gap indicates that the range between interceptor and target is decreasing at a speed proportional to the angular position at which the gap comes to rest. This speed is referred to as the closing range rate. Similarly counterclockwise displacement of the gap indicates that the range between interceptor and target is increasing at a speed (called the opening range rate) proportional to the final angular position of the gap. A fairly accurate indication of the range rate is provided by means of the graduations etched around the periphery of the indicator face.

In developing the circle, a 940-Hz oscillator circuit in the indicator control produces a sine wave which is fed to a phase-shift network, the output of which consists of two 940-Hz sine waves 90° out of phase with each other. These two signals are applied to the horizontal and vertical deflection plates, respectively, thereby producing a circle on the screen. The range-rate is generated by applying the oscillator output to another phase-shift network, which produces a single 940-Hz sine wave variable from +40° to -50° with respect to its input. The phase of this signal is adjusted to set the range-rate gap at 12 o'clock when the range rate is zero. This signal is then processed in the circuits of the indicator control and combined with a reference voltage, called the d-c range-rate voltage, from the computer in the CW radar system. The resulting pulse output is then employed as a blanking pulse to the intensity grids of the indicators, thereby producing the required gap at a position on the range-rate circle determined by the amplitude of the d-c range-rate voltage.

During track operation, the radar display also includes a circle of varying diameter, which represents the allowable steering error within which successful missile launch can be made. If lockon is achieved at the maximum limit of the AI (air intercept) ranges (50 miles), only a very small steering error can be tolerated at that distance, and the ASE circle may close to its minimum size of 0.4 inch in diameter. The size of the circle then increases as the range decreases, until it reaches its maximum size at the moment that the IN RNG (IN RANGE on pilot's indicator) lamp on the indicator bezel lights up. The lighting of the IN RNG lamp indicates that the target range is now within both the maximum aerodynamic limits and the maximum seeker limits of the selected missile. As the range decreases from this point, the size of the circle begins to decrease too, to acount for the decreasing flying time during which the missile can correct for a steering error. The ASE circle reaches its minimum diameter as the target range reaches R_{min}, the minimum launch range for the selected missile. Beyond the R_{min} range, the entire track presentation disappears and the breakaway-X symbol is presented.

For systems with SEAM, a SEAM circle is displayed during SEAM operation and the ASE circle is extinguished if the radar set is in track. The break-X relay is also disabled in SEAM and no break-X symbol is available.

The ASE circle is generated in the same manner as the range-rate circle except that no blanking pulse is provided to generate a gap, and the 940-Hz deflection signals vary in amplitude to produce a circle of varying diameter. The amplitude variation of the deflection voltages during normal track operation is produced by means of a varying d-c bias voltage obtained from the computer in the CW radar system.

The actual steering error or deviation of the aircraft from its required course, is indicated in the display screen by the position of a moving dot called the steering error dot or aim dot. For a perfect course, the dot would be centered on the display. However, since some deviation can be tolerated, the pilot is merely required to guide his aircraft so that the aim dot stays within the limits of the ASE circle.

The R_{min} strobe included in the track presentation indicates the minimum range at which a missile may be fired. If the target symbol drops below R_{min} strobe at any time during track operation, the IN RANGE lamp goes out. The BREAK lamp lights, the track presentation disappears from the screen and the breakaway X appears as an indication to the pilot that he is too close to the target and must alter his course. The break-away symbol appears in the center of the screen as a script letter X approximately 1 inch high.

The X-symbol is formed by producing a 2:1 Lissajous figure on the screen and blanking out the two ends of the pattern. A 400-Hz sine wave is applied to the vertical deflection plates and a 200-Hz sine wave to the horizontal plates, thereby causing the electron beam to the storage tube to complete two vertical sweeps for every single horizontal sweep.

The symbol-generating circuits described in the preceding paragraphs all operate continuously and simultaneously. It is therefore obvious that if the various symbol signals were to be applied to the deflection plates at the same time, a completely unintelligible display would result. Time-sharing is therefore employed in the A-gun channel, and with the aid of the persistence characteristics of the storage tube, the simultaneous display signals are passed through diode signal switches which are gated in sequence by the outputs of a time-sharing gate generator. From the outputs of these diode switches, the signals are applied to the deflection plates one at a time and in the sequence desired. A complete time-sharing cycle lasts 20 milliseconds, and since the shortest persistence in the storage tube is of the order of 100 milliseconds, the display screen can present the illusion of continuously generated display.

Each of the symbol signals applied to the deflection plates is accompanied by appropriate intensity pulses applied to the storage tube intensity grids; when no deflection signals are being applied, the display screen remains blanked out. The intensity pulses are adapted, in amplitude and duration, to the sizes and writing speeds of the individual symbols, thus allowing a composite display of uniform brightness to be presented on the screen. In addition, several of the symbols have certain peculiar requirements which are most easily served by means of intensity control. Examples of these symbols are: the range-rate circle, in which the position of the gap is determined by a properly timed blanking pulse; the breakaway X which has an intensity pulse timed to blank out the ends of the symbol; and the elevation strobe, aim dot, data link dot, and SEAM dot which employ intensity control to prevent the appearance of undesired symbols on the screen.

GENERAL DESCRIPTION OF B-GUN DISPLAY.–The B-gun channel generates the B-sweep, the acquisition symbol, the R_a and R_{min} strobes, the target video, the range strobe, and the bombing range strobe. These symbols are illustrated in the composite A-gun and B-gun displays of figures 8-29, 8-30, and 8-31. The B-sweep and target video appear in all conditions of the radar in which the transmitter is operating. The acquisition symbol appears in all conditions of the system except track; after lockon has been achieved, the acquisition symbol is replaced by the R_a and R_{min} strobes.

Unlike the signals for the A-gun symbols, which are completely independent of one another, the signals generated in the B-gun channel are interdependent, and exercise definite control over each other. The target video and the range strobe are displayed as intensified spots on the B-sweep. When the lockon switch on the radar control stick is pressed to the half-action position, the B-sweep slews to the azimuth position of the acquisition symbol; after lockon the R_a and R_{min} strobes maintain a constant azimuth position with respect to the B-sweep. In addition to this feature of interdependence, the B-gun presentation is synchronized with the repetition frequency (PRF) of the transmitted radar pulses (radar trigger), whereas the A-gun symbols require no synchronization with the action of other portions of the radar set.

The B-sweep appears as a vertical line moving across the width of the radar screen in coordination with the azimuth movement of the antenna. The sweep line is horizontally centered on the screen when the antenna is pointed straight ahead; maximum sweep displacement to the left or right from center represents an antenna swing of 60° when the system is in wide scan. The overall height of the B-sweep line, although constant, may represent a total range of 10, 25, 50, 100, or 200 miles, depending on the setting of the RANGE switch on the radar set control panel.

For each such setting, the range at any intermediate point on the B-sweep is proportional to the height of that point from the base of the display.

It is sometimes necessary to magnify certain portions of the range sweep for a better view of suspected targets. This can be done by selecting a short length of the sweep that represents the range sector of interest, and then expanding that sector to cover the entire height of the display. When the DISPLAY switch on the radar set control is set at the EXP position, the start of the B-sweep is delayed from the radar trigger by an interval corresponding to the distance between the interceptor and the range at which the expanded sweep starts.

The B-azimuth signal, a 400-Hz voltage modulated by a triangular envelope which corresponds to the horizontal component of the antenna motion, is demodulated and filtered, and the resulting signal is applied to the B-gun horizontal deflection plates of the storage tube. This sweep voltage causes the B-sweep to move across the screen, thus indicating the azimuth angle of the antenna scan. During acquisition and track operation, a small 50- to 70-Hz voltage is superimposed upon the horizontal deflection signal, thus producing a dither in the B-sweep and causing it to appear wider to insure its visibility, as shown in figures 8-30 and 8-31. This voltage is the output of the azimuth spin generator, and its frequency corresponds to the nutation frequency of the antenna feedhorn.

approximately one quarter inch apart. The position of the symbol in range and azimuth is controlled manually by the RIO as he moves the radar control stick to the desired position. During search operation the antenna scans automatically, and its position is not affected by the movement of the radar control stick. Nevertheless, the RIO can use the control stick to bracket a desired target with the acquisition symbol, and when the lockon switch on the radar control stick is pressed to the half-action position, the antenna slews to the azimuth position of the acquisition symbol and operates under manual control as shown in figure 8-30. The position of the acquisition symbol is adjusted so that the range strobe, which appears on the B-sweep during acquisition and track, is directly over the desired target. If the lockon switch is next pressed to the full-action position, the radar locks on the target and the antenna begins to track automatically. The acquisition symbol then disappears, and the track presentation illustrated on figure 8-31 is displayed.

The R_a and R_{min} strobes are two short horizontal lines appearing slightly to the left of the B-sweep during track operation. The R_a strobe indicates the maximum target range for firing a missile in a particular tactical situation, taking into account only the maximum aerodynamic range of the missile. This range, which is calculated in the range computer of the CW radar system, is dependent upon such factors as altitude, true air speed, and closing velocity between interceptor and target. When the range between interceptor and target decreases to the point where it is within the limits of both the R_a range and the maximum seeker range of the missile, the IN RNG (or IN RANGE) lamp on the indicator bezel lights. The R_{min} strobe indicates the minimum range at which a missile can be fired and still be capable of receiving CW guidance As the target falls below the R_{min} range, the track presentation disappears from the display screen, and the break-away X appears as an indication to the pilot to alter his course in order to avoid a collision. If the missile is fired at the R_{min} range, the pilot can still alter his course without depriving the missile of its required guidance, provided that the angle at which he breaks away does not exceed the gimbal limits of the antenna.

The R_a and R_{min} strobe signals from the computer are passed through two switch gates which are activated alternately so that each strobe is written on the display screen on alternate radar triggers. The horizontal deflection signal consists of the B-sweep azimuth signal, slightly attenuated, with a 20-KHz signal superimposed to provide length to the strobes.

The target video and the range strobe are both displayed on the indicator screen as intensified spots on the B-sweep. The target video display includes actual targets, details of terrain, and clutter due to jamming interference or weather. During all operating conditions except mapping, the range gate pulse from the synchronizer is applied to the input of the RIO B-gun horizontal deflection amplifier. This short pulse (0.4 microsecond) causes a momentary deflection of the B-sweep, as illustrated in figure 8-29. In the acquisition and track conditions, the B-sweep is intensified at the point of this deflection, and this brightened spot, combined with the dither of the B-sweep, appears as the range strobe.

During search and acquisition the range strobe is generated in the range tracking system as a function of the radar control stick position; during track it becomes a function of range computed in the range tracking system. Although generated continuously, the range strobe signal is permitted to pass to the indicators only during conditions of half action, full action, automatic track, or manual track.

The bombing range strobe provides a range reference in the bomb mode of operation and is used by the pilot and the RIO to determine target ranges. The target position is compared to the known bombing range strobe position.

Of the B-gun symbols which are generated by means of voltages applied to the deflection plates, only two are displayed at any given time. During search and acquisition the displayed symbols are the B-sweep and the acquisition symbol; during track the B-sweep and the R_a and R_{min} strobes are displayed. Time-sharing employed in the generation of these symbols involves two active periods, one of the video display and one for the acquisition symbol (or R_a R_{min} strobes) display, followed by dead time that lasts until the next radar trigger. During the video display period, the B-sweep signals are applied to the deflection plates; during the symbol displayed period, either the acquisition symbol signals or the R_a and R_{min}

strobe signals are applied to the deflection plates, depending on the operating condition. The time-sharing action is accomplished by means of transistor switches which are activated by the gate ouput of the range multivibrator, two of these switches (one horizontal and one vertical) being activated during each of the above-mentioned switching periods.

To generate a visible display on the screen, an intensity signal must be applied to the control grids of the storage tubes at the same time that the vertical and horizontal voltages are being applied to the deflection plates. The amplitude and duration of each of these intensity pulses vary according to the size and shape of the individual symbol, and the pulses must be accurately timed to blank out any undesired portions of the symbols.

CW RADAR SET GROUP

The CW radar set group, utilized with the previously discussed AI type radar missile control system, provides a modulated CW-RF signal which, when transmitted by the antenna of the AI radar, is used to illuminate an airborne target. This signal, when reflected from the target, is used with the modulated CW-RF signal received directly. These signals are used by the CW radar target seeker in an air to air type missile (semiactive homing) to guide the missile toward interception of the target aircraft. It also provides signals for prelaunch tuning and control of the missile and additional signals which are used by the AI radar to provide the pilot with adequate information to fully utilize the capabilities of the aircraft/missile combination.

The CW radar set group is composed of four major units:

1. Computer-modulator.
2. Power Supply.
3. Radar transmitter and cooling system.
4. Flight data computer.

PRINCIPLES OF OPERATION

The CW radar set group utilizes three frequencies. The primary, or magnetron frequency, is normally called the "A" frequency. This is the fundamental CW radio-frequency. However, identification of the signal requires coding of the "A" frequency by frequency modulating it with a frequency referred to as "B". The "A" frequency is also frequency modulated by another frequency, for range information to the missile, by a frequency referred to as "C". The frequency "B" coding signal is also amplitude modulated at the frequency "C" rate and is used for range reference in the missile. Thus, the emission from the AI antenna is actually a CW signal which has been frequency modulated by multiple signals. The purpose of these frequencies is explained later in the chapter.

The power output delivered to the AI antenna from the CW radar will determine the missile's normal control range. This range will vary, depending on the condition of the equipment, atmospheric conditions, and aircraft altitude at time of launch.

The normal type AI radar, when used with the CW system, must be modified with a duplexing arrangement which will render the AI radar antenna capable of handling both CW and pulsed signals simultaneously.

The CW radar set group accepts target range information from the AI radar and computes the target's closing velocity. It is used in conjunction with the launching aircraft's true air speed and altitude data to provide fire control information to the guided missile launching set.

In addition, range data from the AI radar is used by the CW radar set group to produce a simulated Doppler signal that is within the region of the Doppler signal to be received by the missile's target seeker group. The simulated Doppler signal is applied to the missile's speed gate circuits, causing it to lock in the anticipated Doppler frequency region.

Prior to launch (out of range), the CW radar set group transmits pseudo and rear signals to the missile. A portion of the transmitted energy is picked off and fed to the pseudo and rear signal circuits. The psuedo signal is produced by a crystal modulating tee operating as a single sideband generator, mixing two signal inputs from the computer-modulator, with the transmitted energy. The upper sideband output is then coupled to the port and starboard pseudo antenna horns and picked up by the missile. The rear signal is distributed to the rear antenna horns through a magic-T and picked up by the missile's rear receiver. These front and rear signals are compared and effect the tuning of the missile's local oscillator. However, when the pilot closes the master armament switch in the cockpit, the pseudo signal is turned off and the simulated Doppler signal is applied to the missile's speed gate.

The AI radar antenna angle and rates are utilized by the CW radar set group to provide head aim and attitude control voltages for the missile plus lead angle steering signals for use by the AI radar attack display.

Lead angle error signals are used by the lead angle interlock circuit in conjunction with the in-range interlock circuits to prevent firing of the missile when the range is above maximum or below minimum, or lead angle is excessive.

UNIT FUNCTIONS

The basic functions of the CW radar set group and the essential flow of intelligence between major components comprising the missile control system in its missile function are illustrated in figure 8-32. The functions shown are simplified to illustrate the type of information exchanged within the missile control system and do not represent the actual circuit connections.

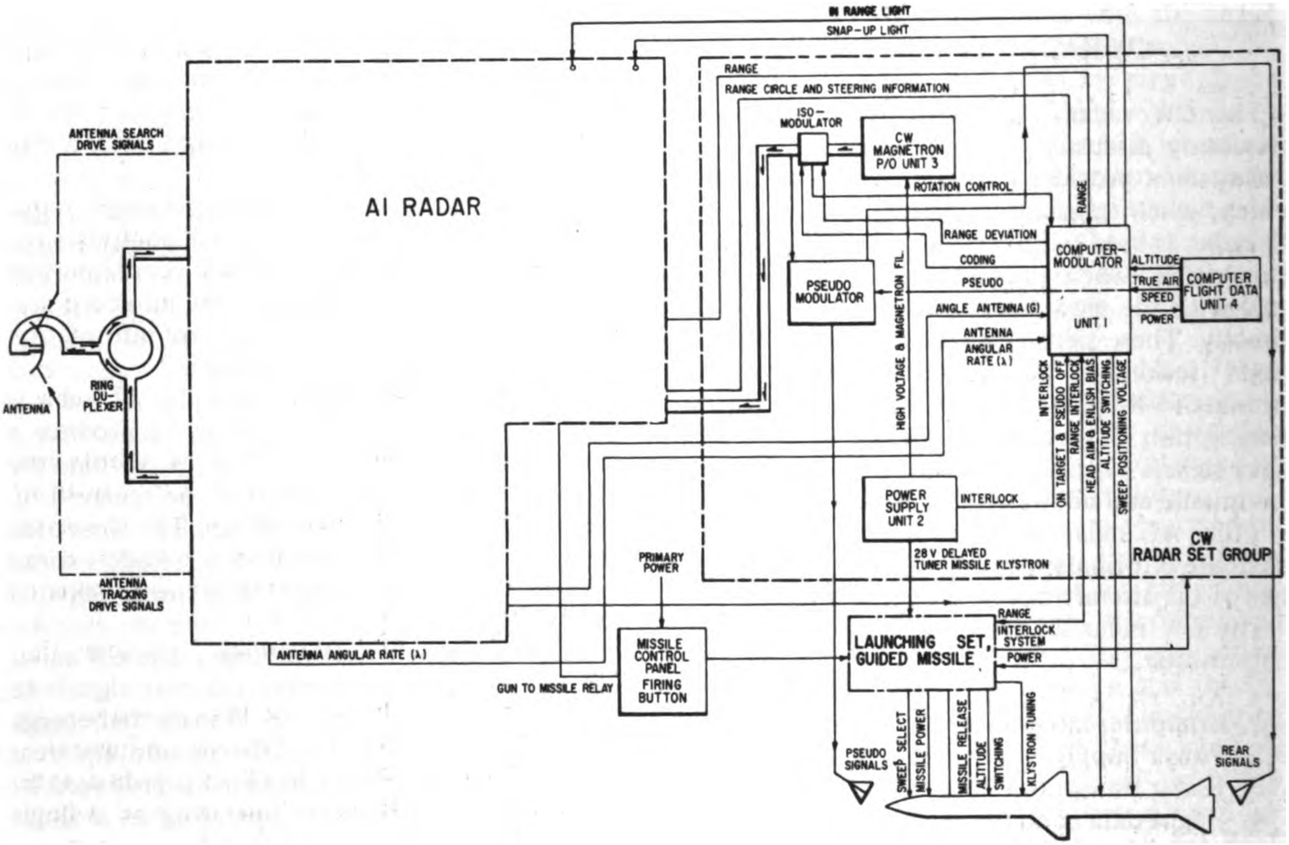

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Figure 8-32.—Functional block diagram of a typical airborne missile control system.

Figure 8-32 should be referred to for the following discussion on the CW radar units' functions.

Computer-Modulator

The computer assembly (lower half of the computer-modulator, unit 1) performs the following functions:

1. Receives and processes target range signals from the AI radar and true airspeed and altitude pressure signals from the flight data computer (unit 4); and furnishes a range interlock to the launching set indicating when a specific target is within range of the missile. These signals are also processed to provide firing range to go, and maximum range information for use by the AI radar.
2. Receives target range and azimuth and elevation rates from the antenna; and furnishes the missile head-aim and attitude control (English-bias) voltages and lead angle steering information (aim-dot) to the AI radar display. The head aim output signal is a summation of antenna rate and position plus range applied to the missile's head control circuits to slave the missile's front antenna with the AI radar's antenna at launch. The English-bias output is also a summation of antenna rate and position plus range applied to the missile's flight control circuits to actuate control surfaces in establishing the proper missile collision attitude. The aim-dot output is fed to the AI radar indicator as the summation of antenna rate and position plus range, providing a lead pursuit course steering aid in the form of a dot on the attack display.
3. Receives and processes altitude pressure data from the flight data computer for use by the missile's autopilot gain control circuit. Thus, with a given angular error, the magnitude of the steering signals applied to the control surface servosystem is a function of the altitude of the missile at launching.
4. Processes the target signal range to provide a simulated Doppler signal which corresponds to the expected signal of the specific target. The simulated Doppler output signal is fed to the missile and locks the missile's speed gate in the region of the target Doppler.

The modulator assembly of the computer-modulator performs the following functions:

1. Supplies the voltage used by a ferrite isomodulator to frequency modulate the CW magnetron/klystron at a frequency "C" rate so as to provide range information to the missile.
2. Provides the voltage used by a ferrite isomodulator to frequency modulate the CW magnetron/klystron at a frequency "B" rate so as to provide coding used to identify the illuminating source to the missile.
3. Amplitude modulates the frequency "B" coding signal at a frequency "C" rate to provide range reference for the CW target seeker of the missile.
4. Provides a frequency-modulated voltage (frequency "C" deviation) to be used to provide artificial target closing velocity and range information (pseudo signal) to effect the tuning of the missile's local oscillators, and to indicate proper missile target seeker operation prior to launch.
5. Accepts and processes information at the ranging frequency from the isomodulator (P/O Unit 3) to effect bias rotation control of the isomodulator. An interlock is included for protection of the CW magnetron/klystron in the event of failure of the bias rotation voltage supply.

High-voltage Power Supply

The power supply provides the filament and high voltage source for the magnetron/klystron. It contains a cam operated time delay circuit for proper operation of the system. This time delay circuit controls the application of the filament voltage to the magnetron/klystron and 28-v d.c. (delayed) to the klystron tuners located in the missile pylons.

The unit is mounted in a pressurized shock-mounted case to allow operation at high altitudes. Cooling is accomplished by means of ram air forced through a plenum chamber where grooves in a cold plate deck aid in extracting heat. Two ports on the case provide air intake and exhaust for the plenum chamber.

Radar Transmitter

The radar transmitter consists of a magnetron/klystron assembly (newer systems utilize a multicavity klystron vice a magnetron), three CW isolators, two additional waveguide couplers, a filter-T assembly, a pseudo modulating T, two magic-T's, two pseudo signal horns, two rear signal horns, and the magnetron cooling system. The radar transmitter performs the following functions:

1. Generates the CW-RF carrier signal.
2. Frequency modulates the CW-RF carrier at a frequency "B" which is the coding signal used to identify the illuminating source to the missile.
3. Frequency modulates the CW-RF output signal with a frequency "C" signal for use by the CW radar target seeker of a missile for range reference.
4. Provides suitable coupling, filtering, and isolation for the CW and pulse RF signals.
5. Single sideband modulates an RF carrier signal with a pseudo Doppler frequency.
6. Distributes and radiates a portion of the FM-CW carrier signal by means of the two rear signal horns.
7. Distributes and radiates the modulated pseudo signal by means of the two pseudo signal horns.

The magnetron assembly is the RF power source of the radar transmitter. It is comprised of a CW magnetron/klystron, an isomodulator with a crystal detector, and associated plumbing.

The microwave power source for CW illumination is a high power type magnetron/klystron operating at "A" frequency. If a target were illuminated with pure CW energy alone, the reflected energy would provide only target speed, target direction, and warhead detonation information to the missile during flight. In order to provide other necessary information to the missile, the transmitted energy is frequency modulated.

This is accomplished through the use of an isomodulator located at the output of the magnetron/klystron. The isomodulator is a ferrite device which is capable of rotating the plane of polarization of its microwave input. Two coils in this device receive "B" frequency and "C" frequency modulating signals from the computer-modulator. The input and output connecting waveguide portions of the isomodulator differ in polarization and, in the absence of modulating signals in the two coils, all of the CW energy is allowed to pass through. When the rotating plane of polarization is caused to depart slightly by the modulating signals, the output polarization is no longer correct for complete transmission. Consequently, a controlled mismatch is created at the output flange of the isomodulator. A portion of the microwave energy is reflected back through the isomodulator input guide to the magnetron/klystron and the isomodulator location is such that this reflected energy pulls the magnetron/klystron at the two modulation frequencies.

The "B" frequency signal which frequency modulated the "A" frequency signal is used for coding. This coding frequency is detected in the missile at the output of the rear IF amplifier and is used to identify the missile with the illuminator of its own launching aircraft.

The "B" frequency is amplitude modulated at "C" frequency providing range reference to the missile.

A "C" frequency signal frequency modulates the "A" frequency signal to provide range information to the missile. The "C" frequency FM is reflected from the target and is received by the missile's front antenna. The "C" frequency signal is extracted and compared with the range reference to detect a phase difference proportional to target range. This intelligence is used by the range arming circuit of the missile.

The CW injection plumbing, consisting of the waveguide and associated detail parts required to inject high power microwave energy into the antenna of the AI pulse radar, is located in the nose section of the aircraft and performs the following functions:

1. Directs microwave energy from the CW magnetron/klystron to the antenna of the AI radar.
2. Prevents CW energy from entering the receiver of the pulse radar and, in turn, prevents pulse energy from affecting the CW magnetron/klystron.
3. Prevents antenna search and scan variations from pulling the CW magnetron/klystron away from its nominal frequency.
4. Provides couplers for picking off energy for the rear and pseudo signal horns.

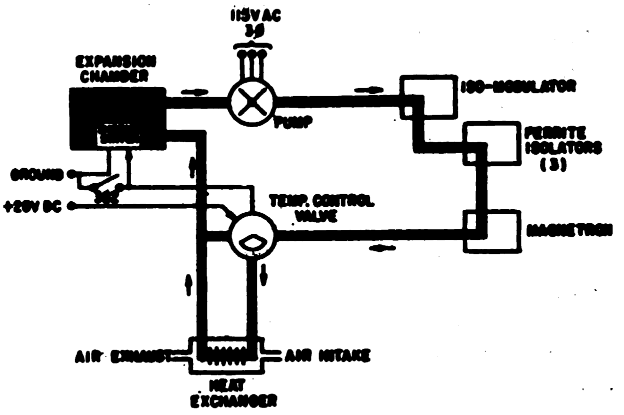
The CW magnetron/klystron is isolated from target reflections which return in the same plane of polarization as the energy being transmitted. The reflected energy, if allowed to enter the output arm of the waveguide, would cause the magnetron/klystron to be pulled off frequency. Three isolators, therefore, are used in the output arm of the waveguide to provide the necessary isolation. The isolator is a ferrite device which is also capable of rotating the plane of polarization of microwave energy passing through it. The ferrite in the isolator is nonreciprocal; i.e., the plane of polarization of energy passing back through the ferrite is rotated in the same direction as the energy being transmitted.

The output waveguide of each isolator is rotated with respect to its input waveguide to allow complete transmission of the energy entering the isolator. Positioning of the input guide of each isolator in the series is automatically governed by the plane of polarization of the energy leaving the preceding isolator (or isomodulator in the case of the isolator in the series). Consequently, the vertically polarized energy which enters the isomodulator is rotated through the action of the isomodulator and the three isolators and is transmitted in the vertical plane of polarization.

Energy reflected from the target is in the correct plane of polarization to enter the transmission line. However, as the energy passes through the isolator, the ferrite rotates it, thereby causing it to be at right angles to the isolator input guide. In this way, the unwanted energy rejected through the nonreciprocal action of the ferrite in each of the three isolators is dissipated in the side arm. A side arm load is located at the input guide in the correct plane to dissipate the unwanted energy.

The magnetron/klystron cooling system is a closed system which dissipates excessive heat from the magnetron and associated ferrite parts. Figure 8-33 is a functional block diagram of the cooling system. It consists of an expansion chamber, pump, temperature control valve, and a heat exchanger.

When system power is applied, the cooling system receives input power to the pump and to a thermoswitch in the expansion chamber. The pump operates continuously, circulating the coolant. The temperature control valve is a three-way valve which controls the return of the coolant to the expansion chamber. If the coolant has been heated to a temperature of 60° F by magnetron/klystron, the thermoswitch closes, applying 28-v d.c. to the control valve. This voltage energizes a solenoid within the valve which, in turn, opens the valve outlet to the heat exchanger. The heated coolant passes through the heat exchanger, where it is cooled, and returns to the expansion chamber. The heat exchanger is supplied with ram air which absorbs the dissipated heat of the coolant.



AQ.289

Figure 8-33.—Magnetron cooling system, functional block diagram.

When the coolant falls below 60° F the thermoswitch opens, causing the control valve solenoid to deenergize. The valve will then direct the coolant back to the expansion chamber, bypassing the heat exchanger.

Switch 3S2, when closed, bypasses the thermoswitch for testing and oil filling purposes.

SCHEDULED MAINTENANCE

The requirements and demands placed on the aircraft maintenance organization for support of the Navy's modern weapon systems have increased substantially. Many separate but interrelated functions and tasks combine to make up the maintenance workload that is required for support of our present day aircraft. The time allocated and available for the accomplishment of this maintenance does not allow for all of these tasks to be considered, planned, and performed on an individual basis. It is necessary that they be combined and sequenced in the proper order if the overall job is to be accomplished in the most efficient manner and within the allocated time. The best possible use of allocated time, manpower, materials, and funds is mandatory if the maximum potential weapon system availability and utilization is to be realized.

The maintenance requirements prescribed as periodic maintenance requirements are the minimum necessary under any conditions to assure timely discovery and correction of latent defects. Compliance is mandatory. Also, the designated calendar intervals are the maximum authorized based on aircraft class and planned service-wide utilization. Due to varying operational requirements, climatic, or environmental conditions, cognizant commanders may increase the scope or frequency of material inspection or examination as required to properly and safely support operations.

PERIODIC MAINTENANCE REQUIREMENTS MANUAL (PMRM)

The PMRM contains the minimum scheduled maintenance requirements directed toward the weapon system. The information in the PMRM is presented in a manner readily usable by maintenance personnel in planning workloads and researching requirements for the weapon system. The manual contains general instructions, preventive tasks, component removal/replacement schedules, accessory record card requirements, and the functional test flight requirements peculiar to the weapon system.

MAINTENANCE REQUIREMENTS CARDS (MRC's)

The maintenance requirements are published on 5- x 8-inch cards in order to provide the maintenance man a ready reference to perform the scheduled maintenance on the weapon system. Each MRC contains one or more detailed maintenance requirement. Illustrations, clearances, tolerances, charts, and part numbers are included when required. All minimum requirements for the accomplishment of any particular periodic maintenance task (preflight, post-flight, daily, calendar, special, or conditional inspection) or portion thereof, are contained in a set of these cards. The work plan, or order of performing the requirements, is prearranged in two manners. The preflight, postflight, and daily work is performed item by item in sequential order arranged on consecutively numbered cards. The calendar inspection work is controlled by the order of arrangement of the items on the MRC's, and in addition, employs an SCC (sequence control chart) for the scheduling of the MRC's. The calendar MRC's are scheduled on the SCC in numerical card number sequence for each required rating.

The man minutes and manhours indicated for the accomplishment of maintenance requirements are provided for use in work planning and scheduling. These figures do not include time spent in resolving equipment or parts shortages, adverse working conditions, nonscheduled maintenance, incorporation of changes and modifications, or shortages in numbers or qualifications of personnel. Time required for preparation is not included. Therefore, maintenance supervisors should consider all such factors as they may apply locally when predicting aircraft out-of-service time.

Maintenance requirement cards are provided in separate decks; e.g., preflight, postflight, daily, and calendar. The MRC's contain all minimum requirements. Daily inspections include 14 days, 28 days, etc.; postflight inspections include "conditional" items, i.e., 100 arrested landings, hard landings, hot start, flame-out, etc., and servicing requirements. The calendar MRC deck consists of a basic portion, called "calendar." These basic calendar requirements must be performed each calendar inspection. The odd and even calendar requirements are items that must be performed every other calendar inspection. These odd and even requirements have been divided to equalize the workload. For record purposes, these inspections are referred to as "odd" calendar and "even" calendar.

No part of any scheduled maintenance is certified on the maintenance requirement cards. Therefore, the MRC's will be used as many times as their condition permits. The certification by maintenance personnel is accomplished on the preflight/daily/in-flight/postflight maintenance record, NavAir Form 4730/2. The calendar periodic maintenance is certified on a MAF.

Locally established periodic maintenance requirements or requirements established by higher authority, not covered by the published MRC sets, can be added to existing cards, which will necessitate an adjustment to the individual card time, plus a possible adjustment of the sequence control chart if the card is in the calendar deck, or by the use of blank MRC's provided for this purpose (NavAir Form 4730/3). When using this method, the new cards generated at the local level can be numbered consecutively following the list number of the published deck (with the designation "local" or assigned suffix letters A, B, C, etc.) and added to the number of the related cards of the published set (also with the designation "local").

A master file copy of current maintenance requirement cards must be maintained with the Maintenance Department. This master file copy will reflect all revisions to the published card sets plus locally added requirements. The Quality Assurance Group is normally charged with this responsibility.

CALENDAR SEQUENCE CONTROL CHARTS

In order to provide a guide for the preparation of the actual calendar maintenance work schedule and a means of controlling the assignment of work and personnel, calendar sequence control charts have been developed and provided as an integral part of the periodic maintenance program. These charts indicate what MRC's are to be compiled with, the number and specialty of the personnel required, the times during which the separate jobs are scheduled for accomplishment, and the "power off", "power on" condition required during the work. The sequence charts have been planned to efficiently integrate all required calendar maintenance so as to effectively reduce the total out-of-service time required for the calendar inspection. The calendar sequence control charts provided may consist of one, two, or three sheets according to the requirements of the aircraft model. It should be noted that calendar SCC's have no application to the preflight, postflight, daily, or progressive aircraft rework requirements. A transparent plastic cover should be placed over the chart when in use to facilitate marking progress. The chart and the plastic cover are therefore reusable.

SPECIAL INSPECTION REQUIREMENTS

All special inspections currently set forth in the applicable HIR or PMRM remain in effect at the specified interval. Such inspection may be performed concurrently with scheduled calendar inspections when the interval authorized for the special inspection is not exceeded. When the interval will be exceeded during the calendar inspection interval, the special inspection must be accomplished as part of the scheduled daily inspection falling nearest to the requirement. Once accomplished, a new interval for the special requirement commences.

INDEX

A
Accountability codes, 57
Acquisition, 216-218, 231
Acquisition-on-jam, 219
Administration of safety program, 25-27
ADMRL, 65
Advancement:
  examination subjects, 10
  how to prepare for, 4
  how to qualify for, 4
  to Senior and Master Chief, 9-10
  to Warrant and Commissioned Officer, 10
Aeronautical allowance lists, 54-58
  purpose and origin, 54
  source and accountability codes, 56
A-gun display, 245-249
AIM-9G missile, 214
Aircraft Application List, 34
Aircraft safety, 24-25
AMMRL, 65
Amplitude modulation, 181
Analysis:
  flow process, 20
  layout, 20
  motion, 20
  spectrum, 86
  work count, 19-20
  work distribution, 19
Analyzer, spectrum, SA-84WA, 86
AN/APM-334, 155
Angle:
  determination, antenna, 138-141
  search, 241-242
  tracking, 236-241
Antenna:
  angle, 138-141
  applications, 145-152
  array, 142-145
  boresighting, 152-155
  characteristics, 135
  cosecant squared, 141-142
  directional properties, 135-136
  feedhorn, 223-224
  scan patterns, 136-137
  types, 141-145
AN/USM-247, 125, 127-131
Application of boresighting:
  for field, 154-155
  short range, 152, 154
Applications, antenna, 145-152
Approach magazine, 23
Appropriation Purchase Account (APA), 49
Appropriations, 48-49
AQ:
  assignments, 3
  billets, 3
  rating, 1
  responsibilities, 3
Army and Air Force publications, 37
Array antenna, 142-145
ASE circle, 248
Astigmatism, 187
Atmospheric modulation, 202
Audits, quality assurance, 17
Aviation safety, 23
Aviation Supply Office (ASO), 46, 48
  responsibilities, 48
Avionics support equipment, 86

B
Back bias:
  amplifier, 225-226
  operation, 241
Backward wave oscillator, 177-182
Beam:
  miser, 180-182
  rider guidance method, 209-210
B-gun display, 249-251

Bibliography for Advancement Study, NavTra 10052 (Series), 6
BIT system, 131-133
  operation, 132
Boresighting, antenna:
  applications, 152-155
  method, 152
  purpose, 152
  test set, AN/APM-334, 155
Bulletins, 38

C

Cable measurements, FDR, 121-123
Calendar sequence control charts, 257
Carcinotron, 176-177
Cathode material, 170
Changes, 38
Characteristics, antenna 135
"Chirp radar," 192
Circulators, 159
Classification, 44-45
Coded federal stock number, 52-53
Coherent:
  master oscillator (COMO), 193-194
  MTI, 204-207
COHO, 205
Collinator, 188
Communications, 14
Component:
  and equipment manual, 37
  control section, 60
Computer-modulator, 253
Continuous-wave Doppler MTI, 203-204
Contractor engineering schools, 33
Contrawound helix, 171
Correcting discrepancies:
  adjustments, 70
  Maintenance responsibilities, 70, 71
Correspondence courses, 6
Corrosion control:
  built-in anticorrosion protection, 79
  elements of an active program, 78-79
  evaluating the effectiveness of, 78
  protection of dissimilar metal contacts, 79
Cosecant-squared antenna, 141-142
CVA/CVS NATOPS Manual, 26
CW:
  radar, 251-255
  transmitter, 253-255

D

Data link, 233
DD form:
  1149, 39-40
  1348, 39-40
Declassification, 44
Degenerate mode, 183
Descriptive/identification lists, 56
Digital Voltmeter 5265A, 92
Direct view storage tube (DVST), 185-192
Directional properties, antenna, 135-136
Directives Application List, 34
Directives issurance system, 40-41
Directives, safety, 27
Discrepancies:
  correction of, 70-71
  evaluation of, 69-70
  trends of, 71-73
Discrepancy trends:
  analyzing deficiencies, 71-73
  inspection procedures, development of, 73
Display, radar, 242-251
Distribution system:
  primary stock points, 51
  reserve stock points, 51
  satellite stock points, 51
  secondary stock points, 51
Documentation of training, 30
Double lobe system, 138-141
Duplexer, ring, 159-165
DVST, 243
Dytronics Model 24D, phase-angle voltmeter, 109-110

E

ECM, 166, 176, 192, 193, 202-203
EFC circuits, 226-230
Electromagnetic interference:
  control of, 79-80
  general sources of, 80
  radar systems, 81-83
  reduction of, 83-85
Electron gun, 170
Electronic Counter 5245L, 92
Electrostatic focusing, 175
English-bias information, 213
Enlisted rating structure, 1
Equipment and Subject Applicability List, 34-35
Evaluating discrepancies, debriefing flight crews, 69-70
Evaluating procedures, 15

F

Factors:
  practical, 4, 5

knowledge, 5
FAETU, 32
Faraday rotation, 158
Far field boresighting, 154-155
FDR:
  analysis, 119-121
  loss display, 119
  versus TDR, 117-119
Federal stock numbers, 52-53
Ferrites, nonreciprocal, 157-159
Film Catalog, U.S. Navy, NavAir 10-1-777, 9
Flow process analysis, 20
Formal inservice training, 29
Frequency domain reflectometry:
  analysis, 119-123
  application, 123-124
  cable measurements, 121-123
  conclusion, 124
  loss display, 119
Fundamental frequency, 86
Funding:
  aircraft operating funds, 49
  Air Staff Administration and Operations Funds, 50
  aviation maintenance funds, 50-51
  aviation outfitting funds, 50
  fleet funding, 51
  fleet outfitting equipment funds, 50
  OPTAR funds, 51
  temporary additional duty travel funds, 50

G

General rating, 1
Ground support equipment (GSE), 64-65
Group 1 material, 44
Group:
  1 material, 44
  2 material, 44
  3 material, 45
  4 material, 45
GSE manuals, 37
Guidance methods, 209-211

H

Head-air information, 213
Helix:
  attenuation, 167, 173
  circuit, 171
  type traveling wave amplifier, 167
Home-on-jam, 219
Homing guidance method, 210-211

I

Illustrated Parts Breakdown (IPB), 53-54
Illustrated shipboard shopping guides, 56
Index, publications, 33
Individual material readiness list (IMRL), 65-68
  cross reference section, 66
  definition of columns,66-68
  maintenance of the IMRL, 68
  multiple application section, 66
  single application section, 66
Informal inservice training, 30
Initial outfitting lists, 55
Inspectors, training of, 16
Interdigital:
  delay line, 179
  line, 173
  magnetron, 179
Interference, electromagnetic:
  control of, 79-80
  general sources of, 80
  radar system, 81-83
  reduction of, 83-85
Interim technical directives, 38
Interservice training, 33
IPB's, 37

L

Layout analysis, 20
Leadership, 4
Library, technical, 38-39
LIFMOP filter, 198-199
Linear array antenna, 143

M

Maintenance:
  information records, 30
  Instructions Manuals, 37
  procedures and special problems, 69-85
  Requirements Cards (MRC's), 256-257
  special problems:
    atmospheric conditions, 75-77
    fungus, 74-75
    humidity, 74
    pressure effects, 75
    temperature, 75
Management:
  branch, 17
  maintenance, 12-13
  personnel, 22-23
Manuals, technical:
  policy, 36
  types, 36-37

Manual track, 233
Master locator index, 54
Material:
  control, 46-68
  identification, 51-54
  identification aids, 53-54
  requisitioning, 58-64
  high value asset control material, 64
  material control division, 60
  material control register, 60
  MILSTRIP, 61
  preexpended bins, 63
  rotatable pools, 64
  supply activity, 58-60
M-BWO, 177
Mech magazine, 23
Mercury delay line, 206
Method of boresighting, 152
Military Requirements for Senior and Master Chief Petty Officer, NavTra 91209, 10
MILSTRIP, 39-40
Missile:
  control system, 211-213
  fire control problem, 208-209
Monopulse:
  amplitude comparison, 146
  phase amplitude comparison, 147
  phase comparison, 146
Motion analysis, 20

N

Narrowband amplifier, 225
Narrowband operation, 241
NATOPS Manual, 26, 36
NavAir:
  00-500A, 34
  00-500B, 34
  00-500C, 34
  00-500D, 34
  10-1-777, 9
  form 5605/3, 39
Naval:
  leadership program, 4
  supply, organization and function, 46-51
Naval Aeronautic Publications Index, 34
Naval air rework facilities, 32
Naval Air Systems Command (NavAir), 48
Naval Material Command, responsibilities of, 46-48
Naval Supply System Command (NavSup), 46-47
NavMat Publication P-5100, 26
NavPers:
  10052, 5, 6, 10
  10061, 6
  15909 (Series), 3
  18068 (Series), 1, 5, 10
  10387 (Series), 3
NavSup 2002, Section VIII, Parts C and D, 33
NavTra:
  1414/1, 4, 8
  10052, 12
  91209, 10
New developments, 9
Nondegenerate mode, 183
North Atlantic 202BR phase angle voltmeter, 109
Nutation, 238

O

Operational manuals, 36
OpNav Instruction:
  3750.6 (Series), 26
  4790.2 (Series), 11, 26
Ordnance Publications, 37-38
Organization of safety program, 25-27
Organizing training program, 28-29
Oscillator, pulsed, 87
Oscilloscope:
  applications, 98-108
  delayed sweep tune, 105-106
  phase difference measurements, 104
  sweep capabilities, 98
  Tektronic Type 453, 92-108
  time-difference measurements, 104
  time-duration measurements, 103-104
  voltage, 99, 101-103

P

Palmer scan, 241
Parametic amplifiers, 182-185
Periodic Maintenance Requirements Manual (PMRM), 37, 256
Periodic permanent magnet focusing, 174-175
Permanent magnetic focusing, 174
Persistence, 190-191
Personnel:
  management, 22-23
  security indoctrination, 43-44
  training, 27-28
Phase angle voltmeters:
  Dytronics Model 240, 109-110
  general, 108-109
  North Atlantic 202BR, 109
Pilot lockon mode, 218, 231-232

Planar array antenna, 143-145
Polarization, 223
PRF, 189, 191
Proficiency pay, 9
Pseudo signal, 212
Publications index, 33
Pulse expansion and compression, 192-203
Pulse-modulated Doppler MTI, 204
Pulse modulations, 181
Pulsed oscillator, 87

Q

Quality assurance, 15-17
"Quals" manual, 5

R

Radar operation:
  acquisition, 216-218, 231
  acquisition-on-jam, 232-233
  angle search, 241-242
  angle tracking, 236-241
  display system, 242-251
  home-on-jam, 232
  pilot lockon mode, 231-232
  range tracking, 234-236
  search, 215-216, 231
  standby, 215
  track, 218-220, 232
Radar systems interference:
  local oscillator radiation, 82
  magnetrons, 82
  modulators, 81
  radar to radar, 83
Radar theory:
  transmitting system, 220-224
  receiving system, 224-230
Range resolution, 192
Range tracking, 234-236
Rate Training Manuals, 6
Ratings:
  general, 1
  service, 1
Record of Practical Factors, NavTra 1414/1, 4, 8
Repair and calibration procedures, 133
Repeater jammers, 202-203
Required reading, 30
Ring duplexer, 159-165

S

SACE, 125, 126, 127
SA-84WA spectrum analyzer, 86
Safety, 23-27
Safety center, 24
Scan patterns, antenna, 136-137
Scheduled maintenance, 255-257
Schools, training:
  Air Reserve Training Command, 32
  class A, 31-32
  class B, 32
  class C, 32
  class O, 32
  class P, 31
  FAETU, 32
  NAMTG, 32
SEAM, 214, 233-234
Search operation, 215-216, 231
SecNav Instruction:
  5210.11, 40
  5212.5, 42
Security, 42-45
Service rating, 1
Ships safety bulletin, 23-24
Short range boresighting, 152-154
Sideband inversion, 200
Signal-to-noise ratio, 202
Simultaneous lobe comparison systems (monopulse), 145-149
Single lobe system, 138
Slow-wave structure, 167
Solenoid focusing, 174
Source codes, 56
Source, maintenance, and recoverability codes (SM&R), 57
Space harmonics, 180
Spatial harmonic circuits, 172
Spectrum analysis, 86-88
Spectrum analyzer, applications, 91
Spectrum Analyzer SA-84WA, 86-89
Stowage of equipment, 22
Subject classification codes, 41
Supervision, 13-14
Supply response section, 59
Supply support center, 58-59
Support equipment:
  avionics, 86
  repair and calibration, 133
Synchronous phase velocity, 180

T

Tactical manuals, 36-37
TDR, 110-116
  (see also time domain reflectometry)
Technical directives, 36, 38

Technical library, 38-39
Technical manuals, 35
Tektronic oscilloscope type 453, 92-108
Test bench, SACE, 126, 127
Test station, VAST, 129-130
Time domain reflectometer model 1415A, 110
Time domain reflectometry, 110-116
Time sequential lobe comparison system, 149
Track operation, 218-220, 232
Track while scan, 151-152
Training, 8, 16, 27-33, 43
Transmitting system, 220-224
Traveling wave parametric amplifier, 184
Traveling wave tube (TWT), 166-177
TR tube, 223

U

Uniform material movement and issue priority system (UMMIPS), 61-63

V

Varactor, 184
VAST, 125, 127-131
Vc circle, 247
Voltmeters:
  digital, 5265A, 92
  phase angle, 108-110
VSWR, 182
VTAS guidance method, 209

W

Weapon equipment lists, 56
Weekly summary of major aircraft accidents, 23
Work center, 21-22
Work count analysis, 19-20
Work distribution analysis, 19
Work simplification, 18-20

Z

Zero defects, 17-18

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